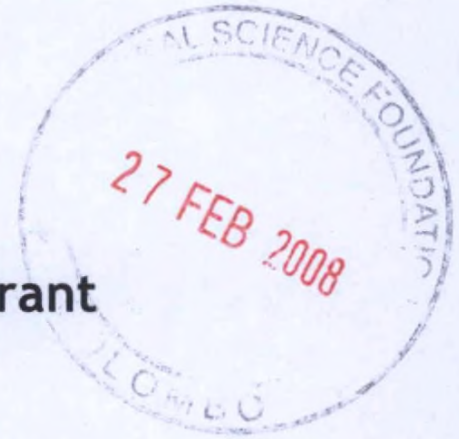


Final Report on the Research Grant
RG/2002/B/01



**Pollution abatement function of a
freshwater wetland and phytoremediation
potential of selected wetland macrophytes
with respect to nutrient and heavy metal
uptake**



FR 1691

FR 1691

Section 1

Information regarding Project/Project Personnel

- i) Contract Number: RG/2002/B/01
- ii) Title of the Project: Determination of the potential and feasibility of fresh water, wetlands for wastewater treatment"

According to the comments of the reviewers, title was altered as

"Pollution abatement function of a freshwater wetland and phytoremediation potential of selected wetland macrophytes with respect to nutrient and heavy metal uptake

- ii) Principal Investigator: Dr (Mrs) M.D. Amarasinghe
- iii) Co-Investigators: Dr (Mrs) J.A. Liyanage
- iv) Institute(s) where research was being carried out: Departments of Botany and Chemistry, University of Kelaniya
- v) Date of award: 01.02.2002
- vi) Date of completion of Project: 31.12.2006
- vii) Total allocation of funds (Rs) : 730,400.00
- viii) Total spent (Rs) : 632,000.00
- ix) Number of Research Students employed: 01
- x) Post graduate degree completed with dates : M.Phil. (thesis has been submitted on the 01.009.2007
- xi) Number of Technical Assistants and/or labourers employed and period of service: 01
- xii) Publications/Communications arising from the project during the reporting period:

K G S Nirbadha, M D Amarasinghe and J A Liyanage, '*Sri Lankan aquatic plants with a potential for phytoremediation of Pb*', International Forestry and Environmental Symposium, November 2007, 12, 44.

Nirbadha, K G S, Liyanage, J A and Amarasinghe, M D, '*Heavy Metals in Substrate of a Freshwater wetland at Kelaniya*', International Forestry and Environmental Symposium, December, 2006, 11, 31.

Nirbadha, K. G. S., Amarasinghe, M. D. and Liyanage, J. A., '*Phytoremediation potential of Iriyawetiya wetland at Kelaniya for heavy metal contaminated urban runoff*', Proceedings of the Sri Lanka Association for the Advancement of Science, 2004, 60, 186.

Amarasinghe, M. D., Nirbadha, K. G. S. and Liyanage, J. A., '*Presence of Heavy Metals in Plants of a Tropical Wetland in Sri Lanka as an Indicator of their relative Phytoremediation potential for Heavy Metal Contaminated Water from Urban Runoff*', 2nd Bangi World Conference on Environmental Management, Malaysia, 2004

Nirbadha, K. G. S., Liyanage, J. A. and Amarasinghe, M. D., '*A Preliminary Study on the Presence of Heavy Metals in Aquatic Plants from a fresh water wetland at Kelaniya*, Proceedings of the Ninth Annual Forestry and Environment Symposium, University of Sri Jayewardenepura, 2004.

Nirbadha, K. G. S., Amarasinghe, M. D. and Liyanage, J. A., '*A preliminary study on the heavy metal contents of two common fresh water Marsh plants Pistia stratiotes and Limnocharis flava in Iriyawetiya wetland in Kelaniya*, Proceedings of the Sri Lanka Association for the Advancement of Science, 2003, 59(I), 170.

Section 2

Executive Summary of the Project:

Use of natural wetlands for pollution abatement has gained attention due to its low operational and maintenance cost when compared to conventional environmental techniques in current use for the purpose. Iriyawetiya wetland is ideally located to receive waste and storm water from the populous Kiribathgoda urban area and hence it was considered important to study its potential use for waste water treatment. Objective of the present study therefore was to determine the sediment, organic matter, nutrient and heavy metal (pollutant) removal potential of Iriyawetiya wetland and also to identify effective wetland plant (macrophyte) species that are able to remove nutrients and heavy metals from water and sediment that can be used in wastewater treatment systems.

Except for phosphorus, Iriyawetiya wetland was revealed to contain high levels of nitrogenous nutrients and heavy metals, i.e. Al, Fe, Cd, Cr, Cu, Mn, Ni Pb and Zn at the inlets through which waste and storm water reaches the wetland. Although average BOD₅ (20.1 ± 3.6 mg/l) and COD (50.4 ± 8.8 mg/l) at the inlets were lower than that of a polluted water, indicating low organic matter content in wetland waters, the average dissolved oxygen (DO) content showed a low average value (2.9 ± 0.2 mg/l) than in a non-polluted water that would have caused due to low densities of phytoplankton and green algae. DO contents however showed a progressive increase towards the outlet. Other pollutants too were progressively decreasing in content towards the outlet, revealing that the wetland abates pollutants in waste/ storm water that passes through it.

The percentage reduction of turbidity, total dissolved solids (TDS) and electrical conductivity was 99% while that for the heavy metals were, Fe (93.5%) Cu (92.25%) Mn (85.32%), Zn (83.6%) Cd (78.5%), Al (77.6%), Ni (71.54%), Pb (68.4%) and Cr (55.71%), indicating the wetlands high efficiency in removing sediment and metal pollutants from the water that moves across it.

According to the values obtained for bioconcentration factor (BCF), *Alocasia macorrhiza* (rooted emergent plant) revealed to be a hyperaccumulator of Fe with a BCF of 85 while floating species, *Pistia stratiotes*, (83) *Salvinia molesta* (73) and *Eichhornia crassipes* (60) ranking second best macrophyte species for the task. *E. crassipes* and *P. stratiotes* were revealed to be the best Ni and Mn accumulators while rooted emergent species, *Limnocharis flava* (BCF = 1821), *Isachne globosa* (BCF = 1817) were the hyperaccumulators of Pb, indicating removal capacities of these plants in removing sediment pollutants. The best Cd, Cr and Cu removers are the floating species, *S. molesta*, *E. crassipes*, indicating their potential to be used for industrial/ agricultural waste water treatment.

Hydroponically grown *P. stratiotes* removed more than 75% of initial Fe in the artificial waste water within 6 days while *E. crassipes*, *I. aquatica* and *L. flava* indicated to be candidate species for phytoremediation for Cd. *I. aquatica* revealed the best species for Cr removal as it has removed > 50% within 6 days and 75% within 9 days. *L. flava* and *E. crassipes* remove more than 50% of low initial Cu content within 6 days. *I. aquatica* is the best accumulator of Pb while *Jussiaea repens* is the only species that removes > 50% of Mn within 14 days, indicating the variation that exists among the phytoremediation potential of wetland macrophytes

Section 3

Report in detail

i) Introduction/background

Urbanization has created massive environmental problems, especially with respect to waste disposal. Urban development in a low-lying area like Colombo and its suburbs has caused increasing pressure on the wetlands. Wetlands are the areas used to discharge and detain storm water, dump waste and also they are reclaimed for housing, urban and industrial expansion .

Pollutants in urban waste, when dispersed in to the aquatic environments get accumulated primarily in surface water and sediment. These pollutants come from either specific discharge points or non-points sources. Urban runoff in to wetlands may include pollutants such as nutrients, toxic substances, oils, pathogens and sediment. Eutrophication due to domestic sewage that contains detergents stimulates plant production and algal blooms. It is also reported that 80 % of all illnesses in the developing world results from unsafe and inadequate water supplies (NARESA, 1991). Safe disposal of effluents or wastewater and surface runoff therefore could be considered an environmental priority.

The discharging wastewater into natural wetlands has been used as a means of disposal since ancient times (McEldowney *et al*, 1993). Such land treatment has prove effective where discharges do not exceed the capacity of receiving system to assimilate, absorb or detoxify contaminants present (Bayes *et al*, 1989). Wetland plants (macrophytes) are used for wastewater treatment (Ennabili *et al* 1998, Brix and Schierup, 1991). Wetlands are reported to possess the ability of reducing pollutants such as suspended matter (turbidity), inorganic nutrients, heavy metals and pathogens in water (Good and Patric, 1987, Kleinmann and Girts, 1987, Reddy and DcBusk, 1987, Cooper and Findlater, 1991)

Preliminary studies indicated that quality of water improves from inlet to outlet of Iriyawetiya wetland located near Kiribathgoda township (Dilhan and Amarasinghe, 2000). Present study therefore was designed to investigate in depth, the capacity of this wetland in performing the function of removing nutrients and selected heavy metals from water that reaches it as well as the phytoremediation potential of wetland macrophytes in performing these functions.

ii) Scientific scope of the project (overall and specific objectives)

Hypotheses

Present study was designed and conducted to test the following hypotheses.

H₁ : Water quality improves when it moves through a wetland.

H₂ : Macrophytes contribute to the improvement of water quality in a wetland and this ability varies among species.

H₃ : Retention of nitrogen, phosphorus, potassium and heavy metals by

wetland sediment contribute to water quality improvement.

H₄: Freshwater wetlands, especially Iriyawetiya wetland could potentially be used as a resource in ecological engineering for sewage or wastewater treatment .

H₄: Hydroponically grown wetland macrophytes can be used to treat wastewater and sewage in small-scale operations

Objectives of the present study

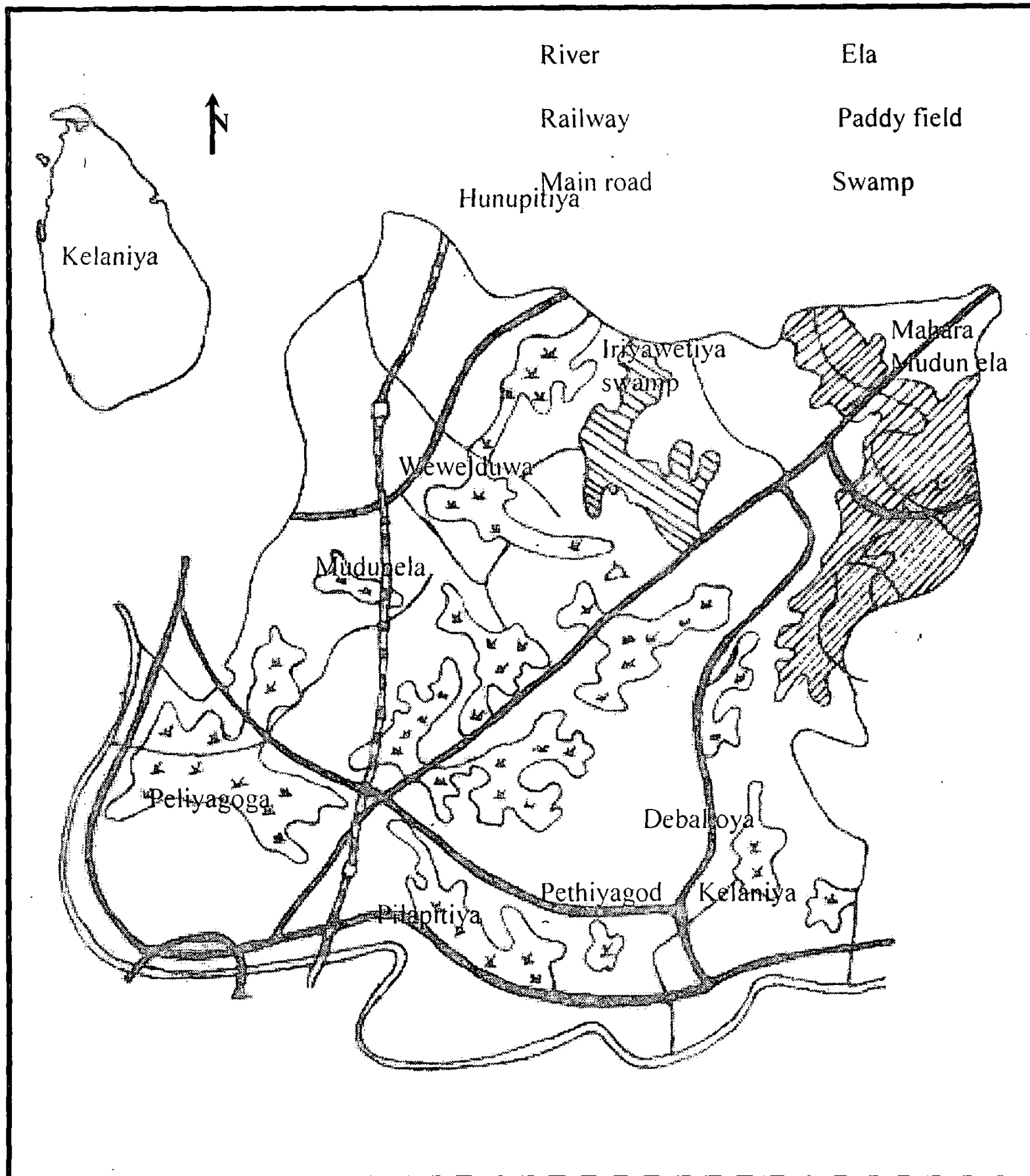
The objectives of the present study therefore are as follows.

1. Determination of nutrient and heavy metal (pollutant) removal potential of Iriyawetiya wetland with respect to removal of nutrients and the major heavy metals (pollutants) in waste/ storm water.
2. Identification of most effective wetland plant (macrophyte) species that are able to remove nutrients and heavy metals from water and sediment that can be used in wastewater treatment systems.

iii) Materials and methods (including statistical methods)

Iriyawetiya wetland, the study area

Iriyawetiya wetland (06°. 59` N, 79°. 55` E) is situated within a distance of 1 km of the university of Kelaniya, in the Gampaha District in Western Province of Sri Lanka. During rainy periods it gets connected to the Muthurajawela peat bog, situated north of Colombo (Fig.1). The total surface area of the Iriyawetiya wetland is 6.8 ha and with a maximum depth of around 4 m and an average of 1 m. There is a one inlet at the northern end of the wetland that brings the urban runoff from Kiribathgoda township. Other man made inlet is situated on the western part of the wetland which brings sewage and storm water to the wetland. The middle and the outlet areas of Iriyawetiya wetland are used for fishing, agriculture and cattle rearing by the communities in surrounding areas. Periphery of the wetland is largely being filled up to create built-up land for residential and commercial purposes.



Sampling sites

Eight sampling sites were selected to represent the inlets, middle and outlet areas of Iriyawetiya wetland (Fig. 2)

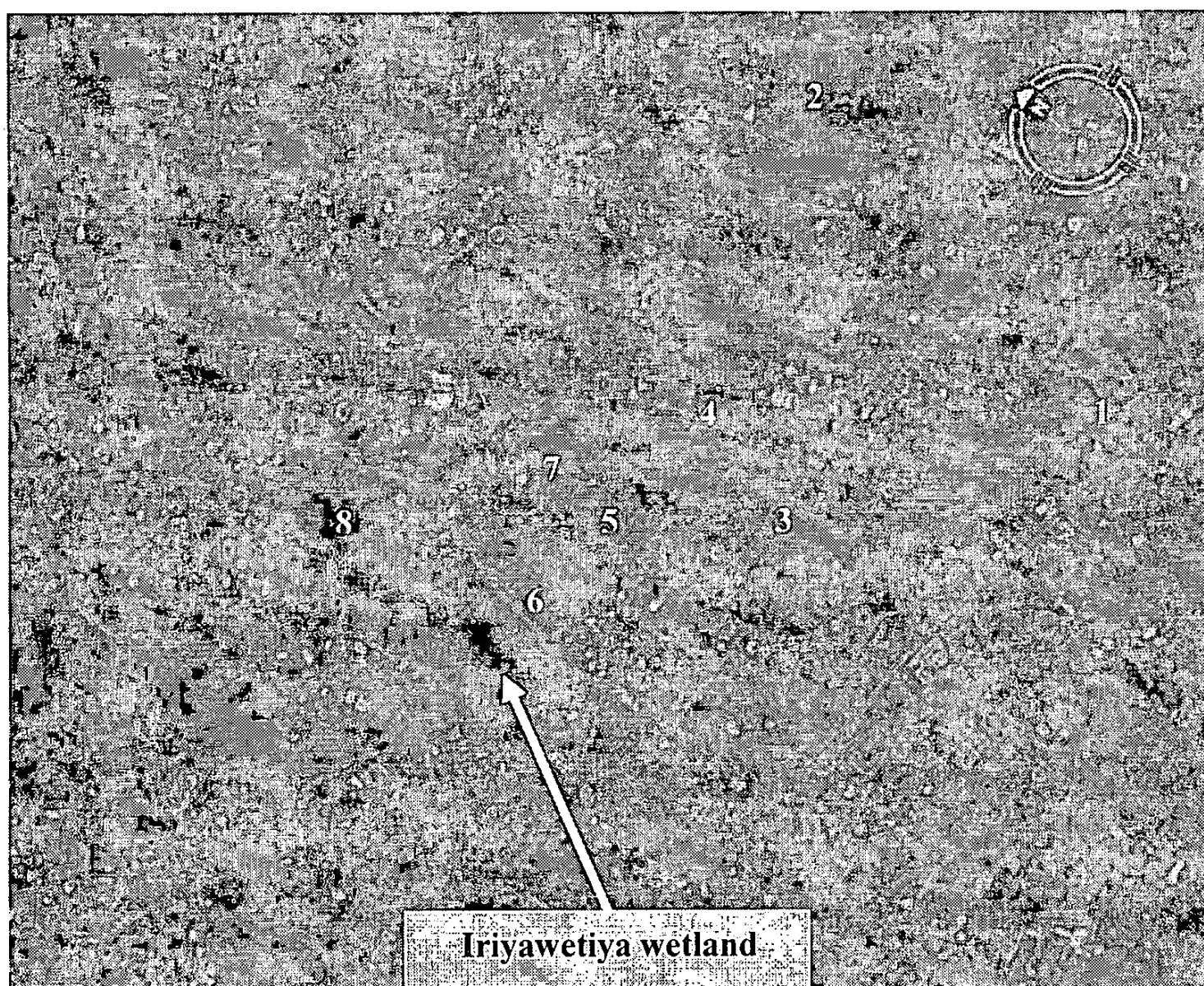


Fig. 2: A satellite image of Iriyawetiya wetland and its surrounding area with location of sampling sites. (In Chapter 4 the same sites are referred to as 1 = I1; 2 = I2; 3 = M1; 4 = M2; 5 = M3; 6 = M4; 7 = M5; 8 = O)

Sampling time-frame

Table 1: Sampling days for water, sediment and plants.

Sampling plan														
Factor	Intervals / months	Sampling period												
		2003				2004				2005				
		Jun	Jul	Sep	Nov	Jan	Mar	May	Jun	Jul	Aug	Oct	Jan	Apr
Water	2	/	/	/	/	/	/	/	/	/	/	/	/	/
Sediment	2	/	-	/	/	/	/	/	/	/	/	/	/	-
Plants	4	/	-	/	-	/	-	-	-	-	/	-	-	-
Density		/	-	/	-	/	-	/	-	-	/	-	/	-

Sampling procedure

Water

Water samples to be analysed for metals and K were collected in 125 ml high-density polyethylene (HDPE) water sampling bottle (Code 1060, Lamatee chem, Chestertown, Maryland, 21620) which have been immersed in 50 % HNO₃ bath overnight and then acid-washed. At each site three samples at distances of 1 m, 5 m and 10 m from the wetland margin were collected and they were preserved with appropriate fixing agents.

Sediment

Three soil/ sediment samples were collected from the sites where wetland water samples were collected using a quadrat of 25 cm x 50 cm area at 1 m, 5 m and 10 m distances from the wetland margin. Prior to obtaining the sediment samples, all the plants in the quadrat were collected from the sampling area using a stainless steel knife. As this vegetation was predominantly floating mat of plants (sods) with some plants attached to sediment, a knife had to be used to separate the vegetation within the quadrat from the rest. A polypropylene auger was used to collect the sediment samples (in triplicate) and the samples were placed in pre-cleaned HDPE bottles (125 ml). Samples were stored on ice while transporting to the laboratory. Immediately after bringing the samples to the laboratory, pH and conductivity of the samples were measured. A sub-sample was placed in shallow pre-cleaned container, weighed and then dried at 21°C for at least 48 hours. The dry sample was re-weighed and placed in an agate mortar and ground and stored in HDPE bottles at 4 °C.

Plants

Quadrat of the size of minimal area 0.5 m² (Dilhan and Amarasinghe, 2000) was placed at 1 m, 5 m and 10 m distances from the wetland margin at each sampling site was used to collect wetland macrophyte (plant) samples. The collected plant samples were placed in plastic bags and brought to the laboratory and washed with tap water and subsequently with de-ionized water. The samples were air dried in the laboratory and shoots of each species were separated from their roots. Shoots and roots were dried at 60 °C for constant weight and store in a polythene bags at 4 °C for further analysis for metals and nutrients.

Characterization of the wetland with respect to pollution abatement function

Physical and chemical properties of wetland water and sediment, i.e. depth, temperature, turbidity, total dissolved solids, conductivity, pH, nutrients, Ammonia nitrogen, nitrites, nitrates, total nitrogen, total phosphorus, potassium, heavy metals, Al, Cd, Cr, Cu, Fe, Ni, Mn, Pb, Zn (after digesting with a mixture of nitric acid, sulfuric acid and perchloric acid in 4:1:1) and using Atomic Absorption Spectrophotometer), dissolved oxygen, biological oxygen demand (BOD₃), chemical oxygen demand (COD) were measured using standard methods from the samples obtained from the eight sites from the wetland. Plant diversity, density, relative density and plant frequency of occurrence were also measured.

Statistical analyses

The mean values of data obtained for each water quality parameter from three sub samples per site, i.e. inlets (two sites), middle area (five sites) and outlet (one site) were pooled and analyzed to identify the underlying variability of water quality in different sites of the wetland with Principal Component Analysis using PRIMER (version 5.2.2) statistical package.

Hyperaccumulation capacity of heavy metals by wetland plant species

Six wetland plant (macrophyte) species that represent floating plants (*Salvinia molesta*, *Eichhornia crassipes* and *Pistia stratiotes*), rooted and partly submerged plants (*Jussiaea repens* and *Ipomoea aquatica*) and rooted emergent plants (*Limnocharis flava*) were selected for the study. Plants were collected from the wetland by hand and brought to the laboratory in plastic basins. The floating species were kept in a freshwater pond and allowed to acclimate to the off-wetland site for one week. Then they were kept in the plastic containers for another week for the same reason. The rooted plants with floating stems were introduced to the containers of the hydroponic system two weeks prior to the commencement of the experiment.

Non-circulating or open hydroponic systems were used for the purpose of investigating the heavy metal removal by plants from the artificial wastewater medium. Nutrient solution was prepared according to modification of Albert's mixture for leafy vegetables. Plastic basins of 15 l- volume were selected as hydroponic containers (0.13 m² in area) and arranged in a green house especially made for the purpose of preventing atmospheric contamination of metals, using thick polythene (Plate 1).

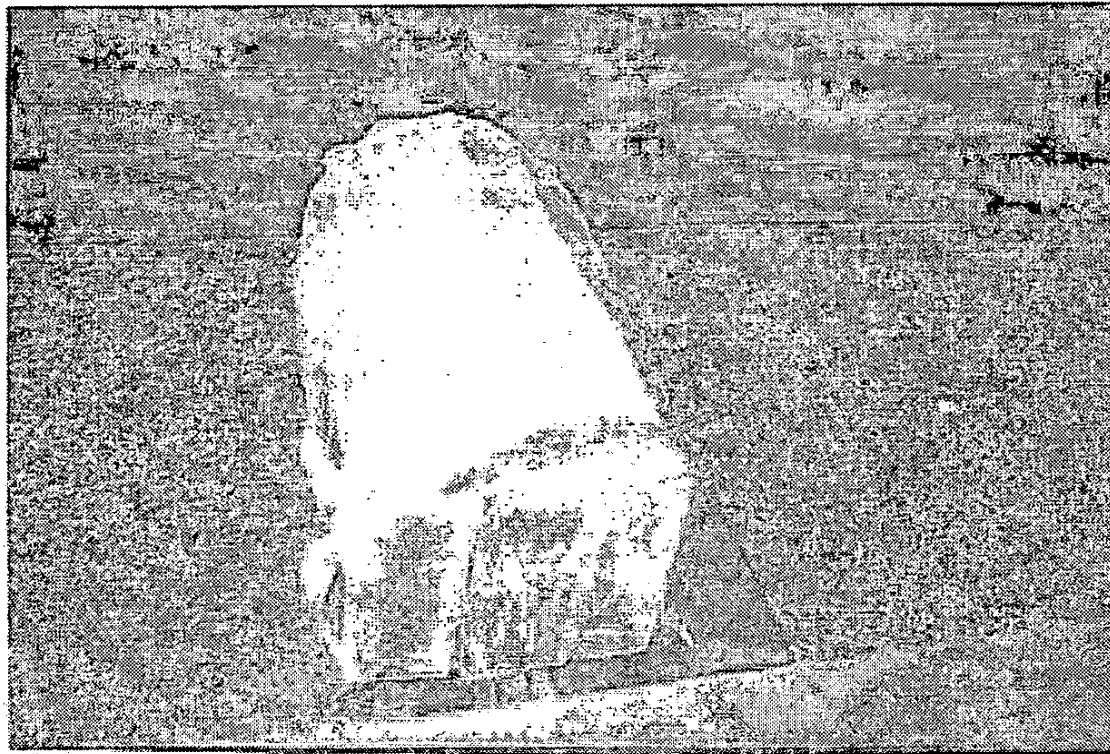


Plate 1: Polythene enclosure in which hydroponically grown plants were kept for the metal uptake experiments



Plate 2: The plastic containers were used to keep the plants at different densities in water with various concentrations of heavy metals

The eight heavy metals that were recorded in high concentrations in the wetland were selected to prepare artificial wastewater. Three initial concentrations, depending on the lowest, highest and intermediate concentrations of each metal that were recorded from water in Iriyawetiya wetland was used for the purpose and hence the three concentrations used for all the metals were not the same (Table 2)

Table 2: The low, medium and high concentration of metals used for the experiment.

Metal	Concentrations (mg/l)		
	Low	Medium	High
Cd	1.00	2.00	4.00
Cr	3.00	5.00	10.00
Cu	2.00	5.00	7.50
Fe	5.00	8.00	10.00
Mn	1.50	3.00	5.00
Ni	0.75	2.00	5.00
Pb	5.00	12.00	24.00
Zn	1.00	1.00	5.00

Plants with similar morphological characters, i.e. number of leaves, average length and breadth of leaves, length of shoot and roots, number of roots and the wet weight of individual plants, were used for the purpose to minimize the physiological differences that might contribute to result differences in metal uptake.

For all plant species, metal uptake rates were measured at three densities (Table 3).

Table 3: Density of plants used for each macrophyte species used in the experiment.

Macrophyte species	No. of plants used per container (0.13 m ²)		
	Low	Medium	High
<i>Salvinia molesta</i>	07	10	14
<i>Pistia stratiotes</i>	05	08	12
<i>Eichhornia crassipes</i>	04	06	09
<i>Limnocharis flava</i>	01	02	03
<i>Jussiaea repense</i>	02	03	05
<i>Ipomoea aquatica</i>	02	03	05

Samples were taken after six, nine and fourteen days of the commencement of the experiment and rates for the three periods were calculated separately to ascertain the best as well as the most economical length of time that these plants could be maintained to remove metals from an aqueous medium. Controls were maintained with the same density of plants only in nutrient solution and all treatments were performed in duplicate. All treatment and control - containers were monitored for temperature, pH (4-6) and conductivity as it was important to maintain these physico-chemical parameters constant throughout the experimental period. Metal concentrations in the hydroponic media with time were measured using the flame atomic absorption spectrophotometer .

iv. Results/ Outputs

Results, discussion and conclusions will be presented under the following subheadings.

1. Characterization of Iriyawetiya wetland with respect to its Pollution abatement function

Mean turbidity of water, along with total dissolved solids [TDS], conductivity (Table and chemical properties, i.e. nutrients, DO, BOD₃, COD and heavy metals(Table 3) showed a gradual decrease from the inlets to the outlet, indicating the pollution abatement function of the wetland.

Table 2: Physical characteristics of Iriyawetiya wetland water during sampling period. (Range is given in the parentheses)

Physical parameter	Inlet 1 (Site 1)	Inlet 2 (Site 1)	Middle area							Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7			
Depth (cm)	57 ± 8 (50- 66)	47 ± 6 (42 -53)	83 ± 14 (71- 98)	116 ± 29 (93 -148)	77 ± 33 (41-107)	104 ± 7 (96 -108)	61 ± 15 (50 - 78)	63 ± 19 (47 - 84)		
Mean depth ± SD	57 ± 8	47 ± 6	88 ± 22							63 ± 19
Turbidity (NTU)	16202 ± 1444 (14780 -17668)	2302 ± 402 (1926 - 2727)	204 ± 17 (185 - 218)	136 ± 23 (123 - 163)	206 ± 16 (189 - 222)	189 ± 23 (165 - 212)	184 ± 10 (174 - 193)	117 ± 3 (114 - 120)		
Mean Turbidity ± SD	16202 ± 1444	2302 ± 402	184 ± 28							63 ± 19
Temperature (°C)	28 ± 1 (27 - 28 1)	28 ± 1 (27 - 28)	27 ± 0 (27- 27)	26 ± 0 (26 - 26)	28 ± 0 (27 - 28)	27 ± 0 (26 - 26)	27 ± 0 (27 - 28)	26 ± 0 (26 - 27)		
Mean Temperature ± SD	28 ± 1	28 ± 1	27 ± 1							26 ± 0

Table 3: Chemical characteristics of Iriyawetiya wetland water during sampling period. The range is given in the parentheses.

Chemical parameters	Inlet 1 (Site 1)	Inlet 2 (Site 2)	Middle area							Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7			
Total Dissolved Solids / mg l ⁻¹	16888 ± 1970 (14853 - 18789)	2201 ± 465 (1756 - 2684)	209 ± 23 (184 - 229)	147 ± 21 (132 - 171)	234 ± 10 (233 - 245)	250 ± 39 (210 - 287)	206 ± 13 (193 - 218)	133 ± 4 (129 - 136)		
Mean TDS ± SD	16888 ± 1970	2201 ± 465	209 ± 39							133 ± 4
Conductivity / μS l ⁻¹	23666 ± 2043 (21675 - 25758)	2821 ± 468 (2422 - 3336)	292 ± 45 (246 - 336)	191 ± 9 (185 - 201)	356 ± 27 (328 - 382)	288 ± 38 (249 - 325)	300 ± 11 (288 - 310)	168 ± 5 (164 - 174)		
Mean conductivity ± SD	23666 ± 2043	2821 ± 468	285 ± 60							168 ± 5
pH	6.26 ± 0.05 (6.22 - 6.31)	7.44 ± 0.13 (7.3 - 7.56)	6.51 ± 0.06 (6.46 - 6.58)	6.41 ± 0.07 (6.33 - 6.46)	6.28 ± 0.09 (6.2 - 6.33)	5.94 ± 0.18 (5.76 - 6.11)	6.46 ± 0.02 (6.45 - 6.49)	7.93 ± 0.13 (7.82 - 8.08)		
Mean pH ± SD	6.26 ± 0.05	7.44 ± 0.13	6.32 ± 0.23							7.93 ± 0.13

Table 4: Nutrients contents of Iriyawetya wetland water during sampling period. The range is given in the parentheses.

Nutrients	Inlet 1 (Site 1)	Inlet 2 (Site 2)	Middle area					Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7	
Nitrite Nitrogen (NO ₂ ⁻)/mg l ⁻¹	3 ± 1 (2-4)	7 ± 1 (6-8)	6 ± 1 (5-6)	10 ± 1 (9-10)	3 ± 1 (2-4)	10 ± 1 (9-11)	4 ± 1 (2-5)	14 ± 1 (12-14)
	3 ± 1	7 ± 1	6 ± 3					14 ± 1
Nitrate Nitrogen (NO ₃ ⁻)/mg l ⁻¹	13 ± 0.05 (12-13)	13 ± 1 (12-15)	11 ± 0.5 (11-12)	14 ± 1 (13-15)	11 ± 2 (9-14)	20 ± 1 (19-21)	10 ± 1 (10-11)	19 ± 2 (17-20)
	13 ± 0.05	13 ± 1	13 ± 4					19 ± 2
Total Nitrogen (TN) /mg l ⁻¹	25 ± 1 (24-26)	27 ± 2 (25-28)	19 ± 4 (16-24)	31 ± 2 (29-33)	18 ± 2 (16-21)	34 ± 4 (30-38)	18 ± 2 (15-20)	34 ± 4 (30-38)
Ammonium Nitrogen (NH ₃ N)/mg l ⁻¹	1.4 ± 0 (1.3-1.4)	1 ± 0 (0.9-1)	1.3 ± 0.1 (1.2-1.4)	0.9 ± 0.1 (.9-1)	0.8 ± 0 (0.8)	0.7 ± 0.1 (0.5-0.8)	1 ± 0.1 (0.8-1.1)	0.8 ± 0.2 (0.6-0.9)
Available phosphorus (AP) /mg l ⁻¹	1.4 ± 0	1 ± 0	0.9 ± 0.2					0.8 ± 0.2
Total phosphorus (TP) /mg l ⁻¹	27 ± 1 (26-28)	21 ± 1 (21-22)	19 ± 2 (17-21)	14 ± 1 (13-14)	21 ± 3 (19-25)	27 ± 2 (26-29)	23 ± 0 (22-23)	16 ± 0 (16-17)
Potassium (K) /mg l ⁻¹	42 ± 1 (41-43)	39 ± 1 (38-40)	29 ± 4 (25-33)	23 ± 1 (21-24)	27 ± 1 (26-28)	37 ± 4 (33-41)	28 ± 4 (25-32)	22 ± 0 (21-22)
Mean K ± SD	30 ± 4 (27-35)	20 ± 1 (19-22)	13 ± 0 (12-13)	14 ± 2 (11-15)	16 ± 1 (15-16)	13 ± 1 (12-15)	10 ± 1 (9-11)	11 ± 1 (10-12)
Mean AP ± SD	30 ± 4	20 ± 1	13 ± 2					11 ± 1
Mean TP ± SD	30 ± 4	20 ± 1	13 ± 2					11 ± 1

Table 5 : Organic parameters (DO, BOD₃ and COD) of Iriyawetya wetland water during sampling period. The range is given in the parenthesis.

Organic parameters	Inlet 1 (Site 1)	Inlet 2 (Site 2)	Middle area							Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7			
Dissolved Oxygen (DO) / mgl ⁻¹	2.9 ± 0.2 (2.8-3.2)	3.4 ± 0.3 (3.2-3.7)	2.8 ± 0.1 (2.7-2.9)	2.6 ± 0.1 (2.6-2.7)	3.6 ± 0.8 (3.1-4.5)	2.8 ± 0.4 (2.4-3.2)	3.1 ± 0.2 (3.0-3.3)	9.7 ± 0.3 (9.4-10)		
Mean DO ± SD	2.9 ± 0.2	3.4 ± 0.3	3 ± 0.4					9.7 ± 0.3		
Biological Oxygen Demand (BOD) / mgl ⁻¹	20.1 ± 3.6 (16.6-23.8)	7.8 ± 0.6 (7.2-8.4)	6.5 ± 0.5 (5.9-7)	4.8 ± 0.9 (4.2-5.8)	6 ± 0.4 (5.7-6.5)	10 ± 7.3 (5.3-18.5)	5.8 ± 0.7 (5.1-6.4)	2.3 ± 0.5 (1.8-2.9)		
Mean BOD ± SD	20.1 ± 3.6	7.8 ± 0.6	6.6 ± 2					2.3 ± 0.5		
Chemical Oxygen Demand (COD) / mgl ⁻¹	50.4 ± 8.8 (41.6-59.1)	20.3 ± 1.5 (18.7-21.8)	16.6 ± 1.4 (15.1-17.8)	12.1 ± 2.7 (10.2-15.1)	15.7 ± 1.7 (14.2-17.6)	26.2 ± 21.1 (12.9-50.6)	15.8 ± 2.4 (13-17.3)	6.3 ± 2.3 (4.1-8.7)		
Mean COD ± SD	50.4 ± 8.8	20.3 ± 1.5	17.3 ± 5.3					6.3 ± 2.3		

Table6: Nutrients contents of Iriyawetya wetland sediment during sampling period. The range is given in the parenthesis.

Nutrients / mg g ⁻¹	Inlet 1 (Site 1)	Inlet 2 (Site 2)	Middle area							Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7			
Total Nitrogen (TN)	45 ± 4 (41 – 48)	40 ± 5 (36 – 45)	26 ± 2 (23 – 28)	30 ± 2 (28 – 32)	26 ± 4 (22 – 30)	24 ± 10 (18 – 36)	21 ± 13 (12 – 36)	29 ± 8 (20 – 37)		
Mean TN ± SD	45 ± 4	40 ± 5	25 ± 3					29 ± 8		
Total phosphorus (TP)	36 ± 5 (32 – 42)	40 ± 12 (27 – 50)	26 ± 1 (25 – 27)	18 ± 2 (16 – 21)	23 ± 3 (20 – 25)	24 ± 8 (18 – 33)	24 ± 3 (21 – 27)	18 ± 2 (16 – 19)		
Mean TP ± SD	36 ± 5	40 ± 12	23 ± 3					18 ± 2		
Potassium (K)	7.6 ± 0.5 (7.1 – 8.1)	5.3 ± 0.8 (4.7 – 6.2)	3.1 ± 0.4 (2.9 – 3.6)	3.2 ± 0.1 (3.1 – 3.3)	4.3 ± 0.9 (3.2 – 4.8)	4.5 ± 0 (4.5)	2.9 ± 0.2 (2.7 – 3.1)	3.9 ± 1.1 (2.7 – 4.8)		
Mean K ± SD	7.6 ± 0.5	5.3 ± 0.8	3.6 ± 0.7					3.9 ± 1.1		

Table 7 : Heavy metals content of Iriyawetya wetland sediment during sampling period. The range is given in the parenthesis.

Heavy Metals	Inlet 1 (Site 1)	Inlet 2 (Site 2)	Middle area							Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7			
Aluminium /g kg ⁻¹	12 ± 3 (9-15)	7 ± 2 (5-8)	15 ± 3 (13-18)	10 ± 4 (5-13)	17 ± 2 (15-19)	8 ± 1 (7-9)	10 ± 3 (8-13)	8 ± 1 (7-8)		
Mean Al ± SD	12 ± 3	7 ± 2	12 ± 4	12 ± 4	12 ± 4	8 ± 1	8 ± 1	8 ± 1		
Iron /mg kg ⁻¹	34 ± 8 (26-41)	14 ± 8 (4-19)	24 ± 10 (13-30)	14 ± 16 (3-32)	5 ± 2 (3-7)	17 ± 9 (11-27)	7 ± 2 (5-9)	4 ± 3 (1-7)		
Mean Fe ± SD	34 ± 8	14 ± 8	13 ± 8	13 ± 8	13 ± 8	17 ± 9	7 ± 2	4 ± 3		
Cadmium /µg kg ⁻¹	1297 ± 705 (578-1326)	535 ± 135 (435-689)	1450 ± 232 (1283-1715)	1115 ± 443 (605-1404)	1698 ± 508 (1382-2284)	926 ± 264 (635-1150)	1099 ± 298 (895-1441)	746 ± 102 (639-843)		
Mean Cd ± SD	1297 ± 705	535 ± 135	1258 ± 311	1258 ± 311	1258 ± 311	926 ± 264	1099 ± 298	746 ± 102		
Chromium /µg kg ⁻¹	61 ± 13 (46-71)	29 ± 1 (28-29)	80 ± 13 (67-93)	46 ± 8 (39-54)	72 ± 11 (64-85)	49 ± 7 (43-57)	60 ± 22 (47-85)	28 ± 5 (25-34)		
Mean Cr ± SD	61 ± 13	29 ± 1	61 ± 15	61 ± 15	61 ± 15	49 ± 7	60 ± 22	28 ± 5		
Copper /µg kg ⁻¹	2640 ± 751 (1957-3444)	4017 ± 298 (3713-4309)	1639 ± 284 (1423-1961)	2851 ± 1532 (1900-4618)	1447 ± 82 (1354-1507)	3276 ± 520 (2961-3877)	2369 ± 544 (1801-2886)	2859 ± 240 (2707-3135)		
Mean Cu ± SD	2640 ± 751	4017 ± 298	2316 ± 779	2316 ± 779	2316 ± 779	3276 ± 520	2369 ± 544	2859 ± 240		
Manganese /µg kg ⁻¹	275 ± 92 (169-331)	8 ± 1 (7-9)	13 ± 1 (12-14)	9 ± 1 (7-10)	12 ± 3 (10-15)	10 ± 2 (8-12)	22 ± 6 (17-28)	15 ± 1 (14-16)		
Mean Mn ± SD	275 ± 92	8 ± 1	13 ± 5	13 ± 5	13 ± 5	10 ± 2	22 ± 6	15 ± 1		
Nickel /µg kg ⁻¹	14 ± 9 (5-23)	2 ± 1 (1-3)	9 ± 3 (6-12)	8 ± 3 (5-11)	9 ± 1 (8-10)	5 ± 2 (3-7)	7 ± 2 (5-9)	3 ± 1 (2-4)		
Mean Ni ± SD	14 ± 9	2 ± 1	8 ± 2	8 ± 2	8 ± 2	5 ± 2	7 ± 2	3 ± 1		
Lead /µg kg ⁻¹	28 ± 21 (7-49)	4 ± 1 (3-5)	12 ± 5 (7-16)	7 ± 2 (5-9)	7 ± 1 (6-9)	6 ± 3 (3-9)	3 ± 2 (1-5)	2 ± 1 (1-3)		
Mean Pb ± SD	28 ± 21	4 ± 1	7 ± 3	7 ± 3	7 ± 3	6 ± 3	3 ± 2	2 ± 1		
Zinc /µg kg ⁻¹	14 ± 13 (2-28)	2 ± 1 (1-3)	12 ± 11 (4-24)	3 ± 1 (1-4)	23 ± 4 (21-27)	4 ± 1 (2-5)	7 ± 2 (6-10)	3 ± 0 (3-4)		
Mean Zn ± SD	14 ± 13	2 ± 1	10 ± 8	10 ± 8	10 ± 8	4 ± 1	7 ± 2	3 ± 0		

Plant diversity and abundance

Table 8 : Species richness and diversity of aquatic macrophytes in the inlets, middle and outlet areas of Iriyawetiya wetland

Area of the wetland	Species richness Margalef index (D_a)	Species diversity Shannon- Wiener index (H')
Inlet 1	4.26 - 4.62	0.73 - 1.7
Inlet 2	4.44 - 5.02	0.81 - 1.07
Middle area	5 - 4.06	0.83 - 1.02
Outlet	4.17 - 4.37	0.80 - 1.05

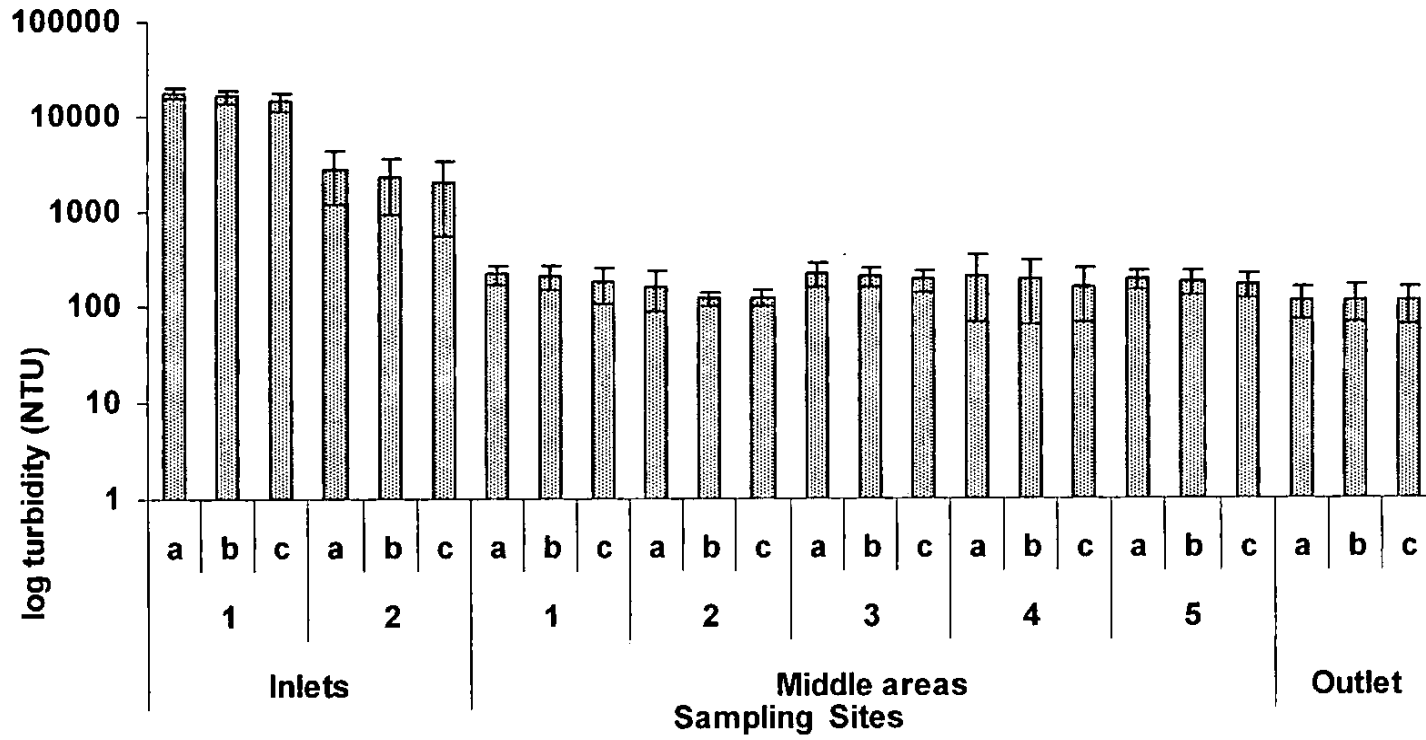
Table 9 : Density (No: of individuals / m^2) of recorded macrophytes from Iriyawetiya wetland during sampling period (Range is given in the parenthesis).

Species	Inlet 1 (Site1)	Inlet 2 (Site2)	Middle area					Outlet (Site 8)
			Site 3	Site 4	Site 5	Site 6	Site 7	
<i>Alocacea macrorhiza</i>	5 (4-6)	4 (2-6)	2 (1-4)	3 (0-5)	3 (0-5)	3 (0-3)	2 (0-3)	4 (0-6)
	5	4			3			4
<i>Alternanthera sessilis</i>	5 (1-8)	16 (13-19)	20 (16-23)	17 (13-24)	15 (7-19)	7 (1-12)	6 (1-15)	10 (0-6)
	5	16			13			10
<i>Commelina diffusa</i>	3 (2-4)	3 (2-4)	10 (7-14)	8 (3-14)	14 (13-15)	3 (1-5)	5 (2-10)	3 (2-4)
	3	3			8			3
<i>Eichhornia crassipes</i>	17 (15-19)	12 (7-15)	10 (2-17)	9 (5-12)	17 (14-23)	2 (0-5)	5 (0-11)	9 (0-14)
	17	12			9			9
<i>Fimbristylis miliacea</i>	5 (1-7)	4 (2-6)	3 (0-5)	1 (0-1)	3 (0-8)	2 (0-6)	1 (0-3)	4 (1-9)
	5	4			2			4
<i>Hydrilla verticillata</i>	0 (0)	0 (0)	0 (0)	0 (0)	4 (0-12)	0 (0)	1 (0-3)	12 (2-17)
	0	0			1			12
<i>Ipomoea aquatica</i>	8 (7-10)	5 (4-6)	8 (6-10)	8 (7-8)	7 (7-8)	9 (8-9)	7 (6-9)	6 (3-9)
	8	5			8			6
<i>Isachne globosa</i>	38 (31-42)	28 (10-28)	24 (2-42)	26 (4-39)	22 (0-37)	20 (0-40)	47 (30-66)	28 (17-43)
	38	28			28			28
<i>Jussia repens</i>	5 (3-7)	4 (2-7)	5 (1-8)	6 (2-8)	6 (2-9)	6 (3-9)	4 (3-7)	6 (3-7)
	5	4			6			6
<i>Limnocharis flava</i>	2 (1-3)	3 (3-4)	2 (1-4)	2 (2-4)	2 (1-4)	2 (2)	2 (1-5)	2 (1-3)
	2	3			2			2
<i>Monochoria vaginalis</i>	4 (3-4)	2 (2-3)	3 (2-3)	3 (2-4)	3 (2-4)	1 (0-1)	2 (1-4)	3 (1-5)
	4	2			2			3
<i>Panicum repens</i>	17 (10-22)	8 (0-25)	9 (0-27)	9 (0-26)	19 (0-36)	6 (0-19)	6 (0-18)	0 (0)
	17	8			10			0
<i>Pistia stratiotes</i>	8 (6-10)	4 (0-9)	8 (4-10)	6 (3-8)	6 (4-12)	7 (1-10)	7 (6-8)	7 (4-8)
	8	4			7			7
<i>Salvinia molesta</i>	6 (2-9)	3 (0-9)	6 (0-9)	3 (2-4)	3 (0-7)	9 (7-10)	9 (1-15)	8 (1-12)
	6	3			6			8

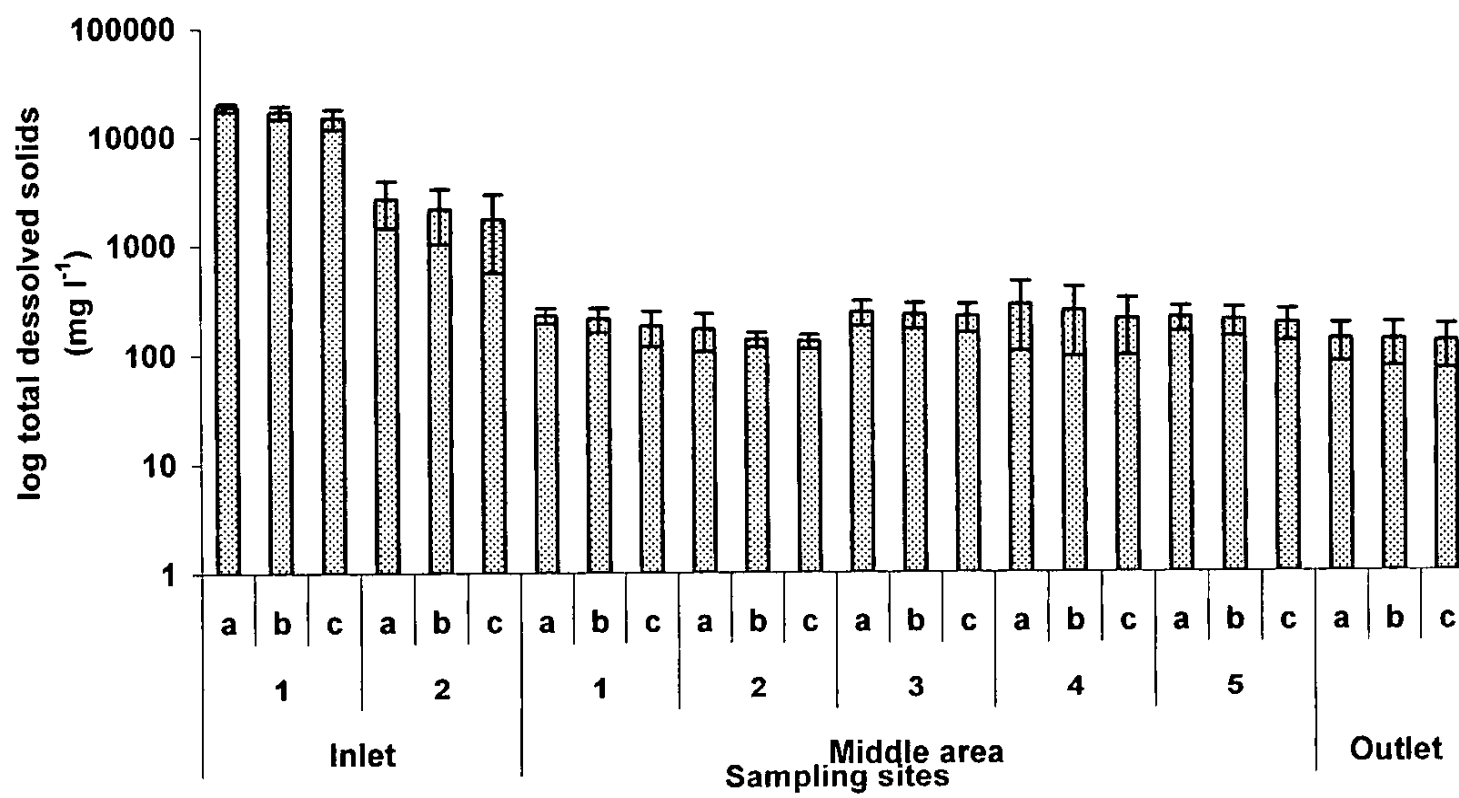
Pollution abatement function of the wetland

The fate of suspended solids (turbidity), DO, BOD, COD (in water), nutrients and heavy metals in water and sediment across the wetland are presented in the following figures.

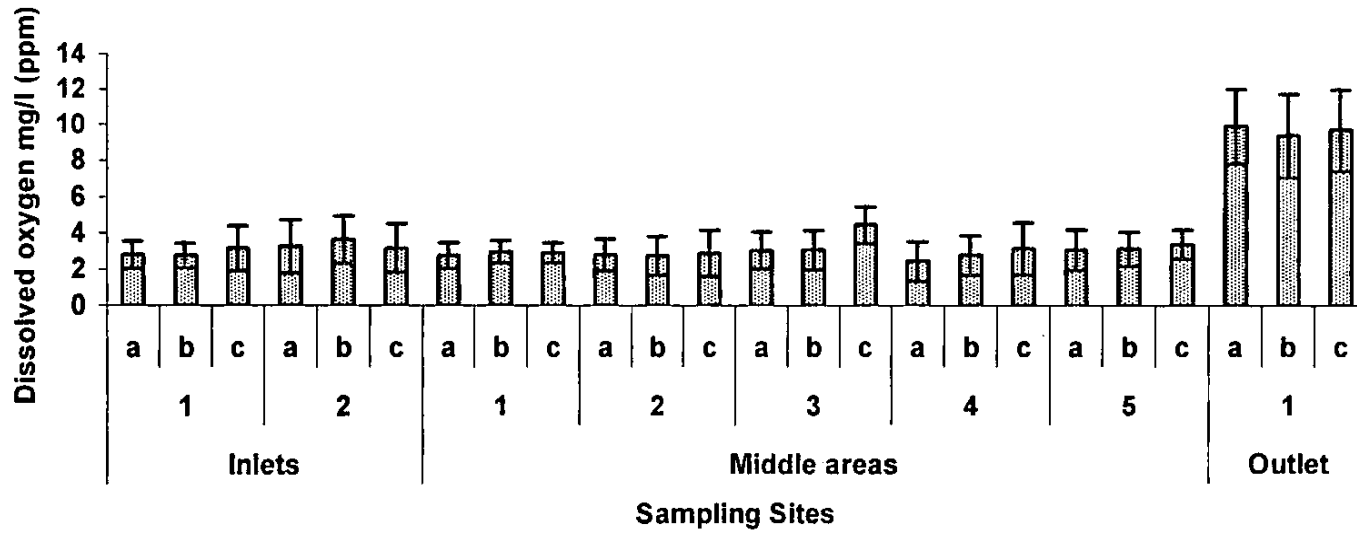
(a) Turbidity



(b) Total dissolved solids

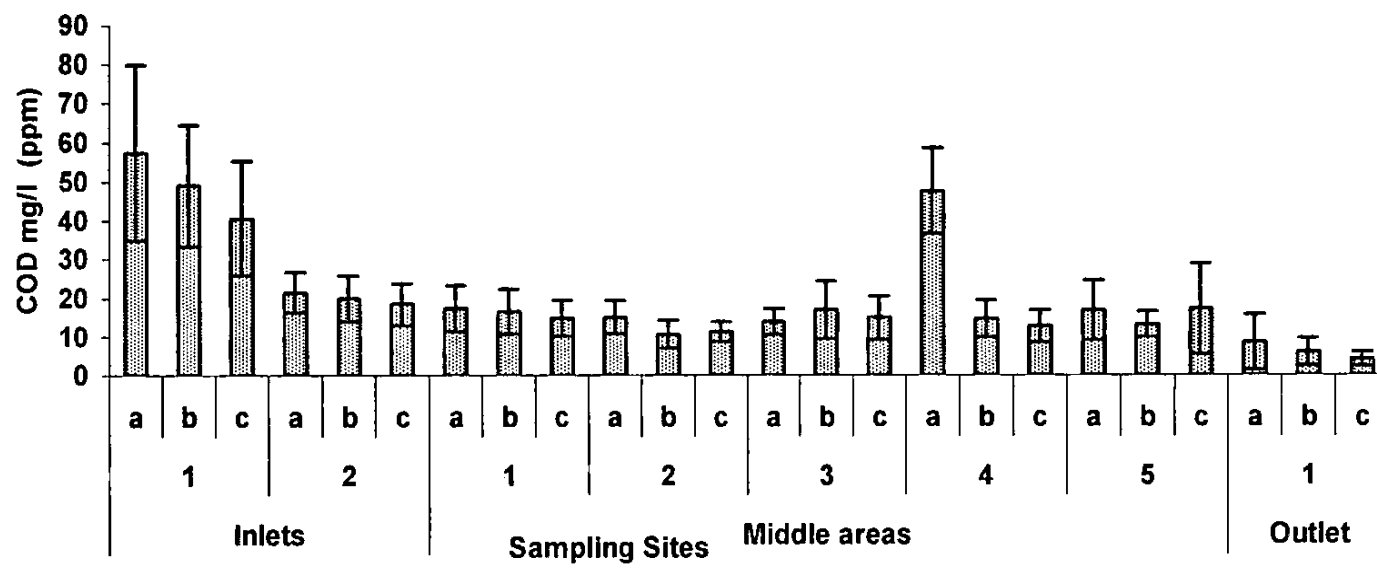


(c) Dissolved oxygen (DO)



(b)

(d) Chemical oxygen demand (COD)



(c)

(e) Biological Oxygen demand (BOD)

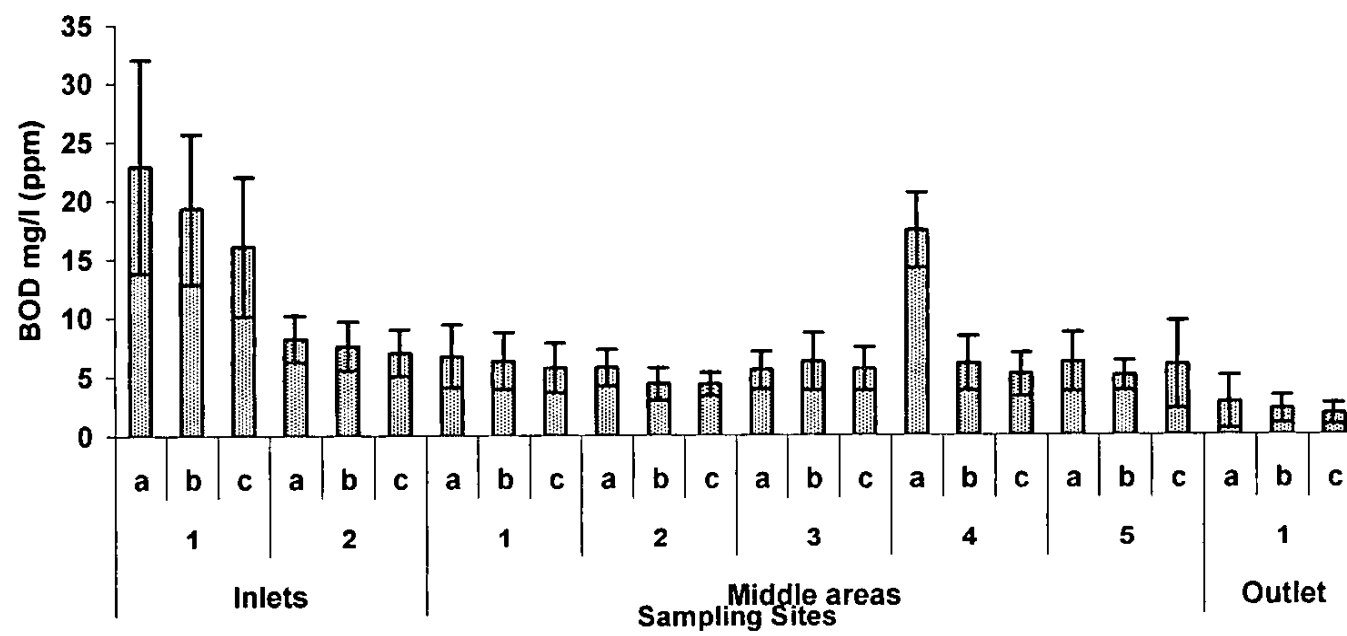


Fig. 3: Variation of pollution parameters across Iriyawetiya wetland.

Principal Component Analysis (PCA) reveals that the pollution status of inlets, middle and outlet sites is distinctly different from each other as shown in the following (Fig. 4) dendrogram.

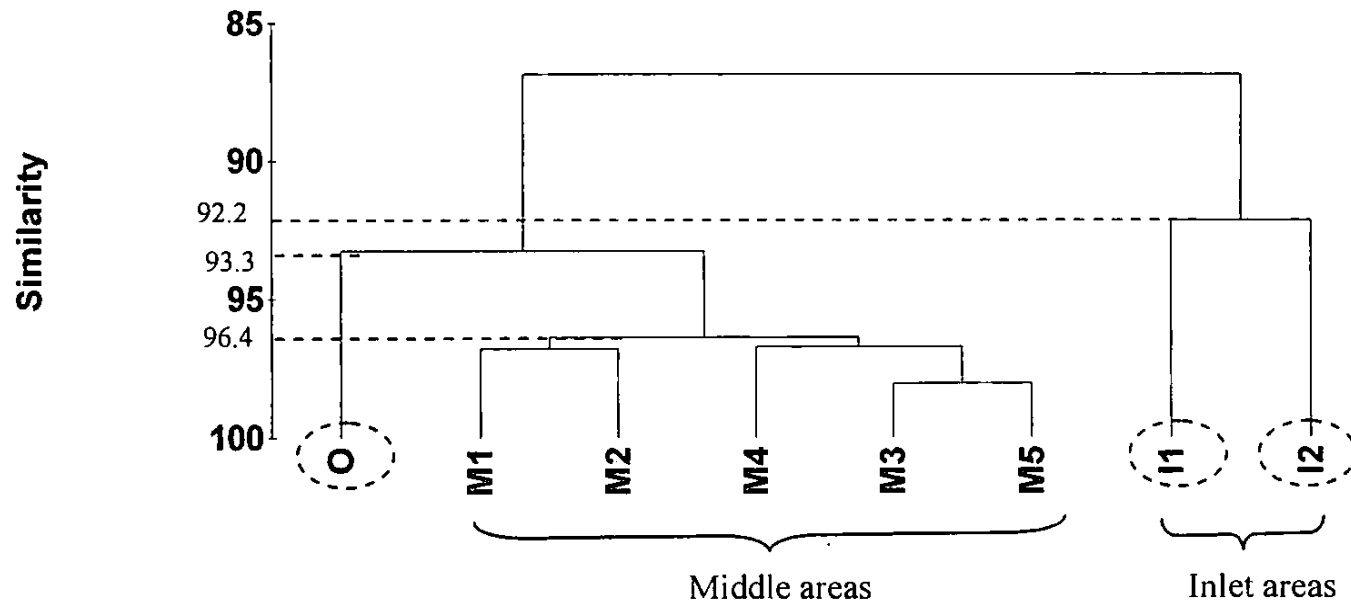


Fig 4 : The dendrogram for the eight sampling sites (two sites in the inlet - I1, I2; five sites in the middle area- M1 - M5 and one site at the outlet - O) in Iriyawetiya wetland based on similarity of water quality parameters.

PCA diagrams such as follows (Fig. 5) shows again that although the sites in the middle area are more similar to each other while they differ from the inlet and the outlet with respect to water quality parameters. The values show that the pollutant contents get reduced across the wetland.

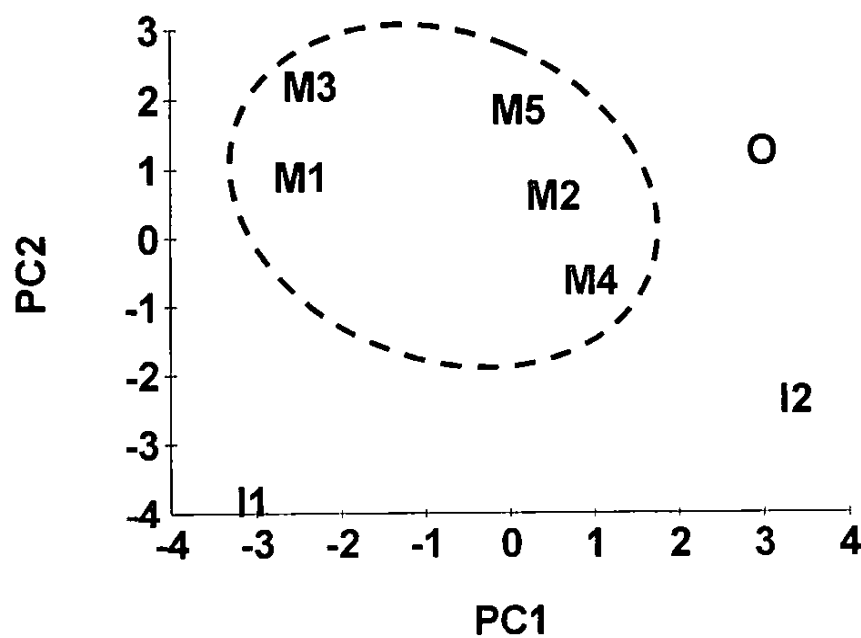


Fig. 5: PCA ordination diagram based on the transformed mean data of the sediment parameters of the Iriyawetiya fresh water wetland.

A similar trend was revealed for the sediment too (Fig.6)

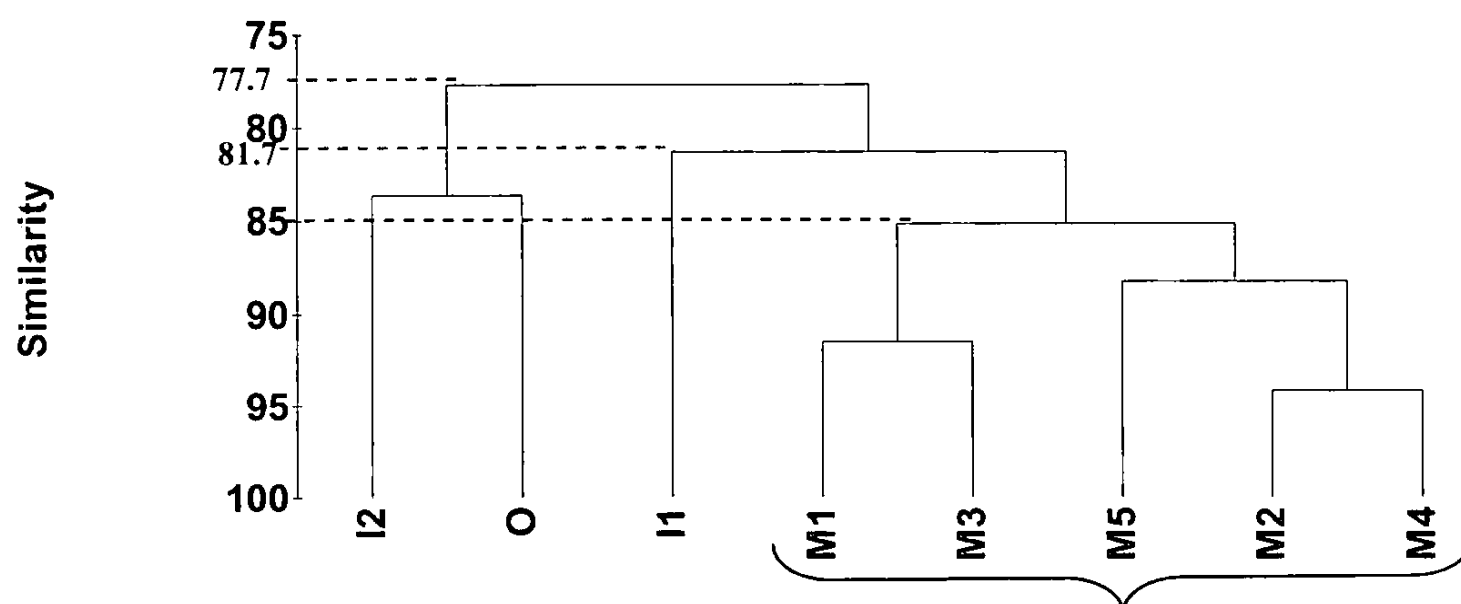


Fig. 6 : The dendrogram of eight sampling sites (five sites of the middle areas, two sites of the inlets and one outlet) in the Iriyawetiya fresh water wetland using sediment parameters.

Table 10: Percentage removal of nutrient and metal from wetland water and sediment and reduction of TDS and EC when water passes through wetland from inlet to outlet.

Parameter	Percentage removal	
	Water	Sediment
Turbidity (NTU)	99.35	
Total Nitrogen (mg l ⁻¹)	34.74	65.59
NO ₃ (mg l ⁻¹)	28.22	
NO ₂ (mg l ⁻¹)	40.20	
Total phosphorus (mg l ⁻¹)	73.33	76.87
Potassium (mg l ⁻¹)	78.18	69.59
Al ppb	77.6	60.22
Fe ppm	93.51	92.22
Cd ppb	78.57	59.28
Cr ppm	55.71	68.27
Cu ppb	92.25	57.06
Mn ppm	85.32	94.75
Ni ppb	71.54	80.23
Pb ppb	68.4	95.01
Zn ppb	83.06	78.72
DO (mg l ⁻¹)	55.60	
BOD (mg l ⁻¹)	91.03	-
Chemical oxygen demand (mg l ⁻¹)	91.72	-
Total dissolved solids (mg l ⁻¹)	99.23	-
Conductivity (μS l ⁻¹)	99.42	-

2. Characterization of wetland macrophytes in accumulation of nutrient and heavy metals

Table 11 : The Bio Concentration Factor (BCF) for eight heavy metals in plant species of wetland

Plant species	Heavy metals							
	Fe	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Floating plants								
<i>Pistia statiotes</i>	83	833	144	307	313	2535	60	1
<i>Salvinia molesta</i>	73	467	521	238	265	1679	36	2
<i>Eichhornia crassipes</i>	60	622	249	229	339	5047	59	2
Rooted and floating stems plants								
<i>Jussiaea repense</i>	26	79	9	20	11	206	56	1
<i>Ipomoea aquatica</i>	31	61	62	15	8	144	36	1
<i>Hydrilla verticellata</i>	9	180	3	56	3	11	34	1
<i>Alternanthera sessilis</i>	31	41	17	14	7	323	46	2
Rooted plants								
<i>Panicum repense</i>	43	51	5	26	8	30	1335	18
<i>Monochoria vaginalis</i>	46	59	11	17	10	122	1569	21
<i>Limnocharis flava</i>	71	90	13	24	11	163	1821	24
<i>Isachne globosa</i>	72	49	9	24	12	34	1817	20
<i>Fimbristilis miliacea</i>	60	71	10	18	11	62	1777	26
<i>Commelina diffusa</i>	43	59	12	13	9	74	1381	18
<i>Alocasea macorrhiza</i>	85	117	12	20	9	181	1279	22

3. Phytoremediation potential with respect to nutrient and heavy metal removal by selected wetland macrophytes

Table 12: Summary of heavy metal removal capacity of the six wetland plant species during 6 days.

Heavy metal	Initial Conc.	Density of plants		
		Low	Medium	High
Fe	Low	-	<i>Pistia stratiotes</i>	<i>Pistia stratiotes*</i>
	Medium			<i>Pistia stratiotes*</i>
	High			<i>Limnocharis flava</i> <i>Ipomoea aquatica</i> <i>Pistia stratiotes</i> <i>Limnocharis flava</i>
Cd	Low		<i>Salvinia molesta</i> <i>Limnocharis flava</i>	
	Medium			<i>Limnocharis flava</i>
	High			
Cr	Low		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>
	Medium		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>
	High	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i> <i>Limnocharis flava</i>
Cu	Low	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i>
	Medium	<i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Limnocharis flava</i>	<i>Eichhornia crassipes.</i> <i>Limnocharis flava</i>
	High	<i>Eichhornia crassipes.</i> <i>Limnocharis flava</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Ipomoea aquatica</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i>
Mn	Low			
	Medium			<i>Eichhornia crassipes</i> <i>Limnocharis flava</i>
	High		<i>Ipomoea aquatica</i> <i>Eichhornia crassipes.</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i>	<i>Eichhornia crassipes.</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i>
Ni	Low	<i>Jussiaea repense</i>	<i>Salvinia molesta</i> <i>Pistia stratiotes</i> <i>Eichhornia crassipes</i> <i>Ipomoea aquatica</i> <i>Jussiaea repense*</i>	<i>Salvinia molesta</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes.</i> <i>Jussiaea repense*</i>
	Medium	<i>Jussiaea repense</i>	<i>Jussiaea repense</i>	
	High	<i>Jussiaea repense</i>	<i>Jussiaea repense</i>	<i>Jussiaea repense</i>
Pb	Low			<i>Ipomoea aquatica*</i> <i>Eichhornia crassipes</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i>
	Medium			<i>Ipomoea aquatica</i>
	High			<i>Ipomoea aquatica</i>
Zn	Low	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes</i>
	Medium	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes.</i>
	High	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes.</i>	<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i>

Table 13: Summary of heavy metal removal capacity of the six wetland plant species during 9 days.

Heavy metal	Initial Conc.	Density of plants		
		Low	Medium	High
Fe	Low		<i>Pistia stratiotes</i>	<i>Pistia stratiotes</i> * <i>Eichhornia crassipes</i> <i>Limnocharis flava</i> <i>Ipomoea aquatica</i>
	Medium			<i>Pistia stratiotes</i> * <i>Limnocharis flava</i>
	High			<i>Salvinia molestra</i> <i>Ipomoea aquatica</i> <i>Pistia stratiotes</i> <i>Limnocharis flava</i>
Cd	Low	<i>Ipomoea aquatica</i>	<i>Salvinia molesta</i> <i>Ipomoea aquatica</i>	
	Medium			<i>Limnocharis flava</i>
	High			<i>Eichhornia crassipes.</i>
Cr	Low	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>
	Medium		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>
	High	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i> * <i>Limnocharis flava</i>
Cu	Low	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes.</i>	<i>Salvinia molestra</i>
	Medium	<i>Salvinia molestra</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i>	<i>Salvinia molesta</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes.</i>
			<i>Limnocharis flava</i> <i>Ipomoea aquatica</i>	<i>Limnocharis flava</i> <i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Ipomoea aquatica</i>
	High	<i>Salvinia molestra</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Ipomoea aquatica</i>
		<i>Limnocharis flava</i>	<i>Limnocharis flava</i> <i>Ipomoea aquatica</i>	<i>Jussiaea repense</i> <i>Limnocharis flava</i>
	Mn	Low		
Medium				<i>Ipomoea aquatica</i> <i>Limnocharis flava</i>
High			<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> *	<i>Salvinia molesta</i> <i>Pistia stratiotes</i> <i>Eichhornia crassipes.</i> *
			<i>Limnocharis flava</i> * <i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>
			<i>Jussiaea repense</i>	<i>Limnocharis flava</i> *

Table contd.

Heavy metal	Initial Conc.	Low	Density of plants Medium	High	
Ni	Low	<i>Jussiaea repens</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	
			<i>Eichhornia crassipes</i>	<i>Ipomoea aquatica</i>	
			<i>Limnocharis flava</i> <i>Ipomoea aquatica</i> <i>Jussiaea repens</i> *	<i>Limnocharis flava</i>	
Medium	<i>Jussiaea repens</i>	<i>Pistia stratiotes</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
		<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
		<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
Pb	Low	<i>Jussiaea repens</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	
			<i>Ipomoea aquatica</i> *	<i>Ipomoea aquatica</i> *	
			<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	
Medium	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
		<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
		<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	<i>Jussiaea repens</i>	
High	<i>Jussiaea repens</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	
		<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	
		<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i> <i>Jussiaea repens</i>	<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i> <i>Jussiaea repens</i>	<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i> <i>Jussiaea repens</i>	
Zn	Low	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	
			<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>
			<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>
Medium	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i> *	<i>Eichhornia crassipes</i> *	
		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	
		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	
High	<i>Eichhornia crassipes</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>	
		<i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i> *	<i>Eichhornia crassipes</i> *	
		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i>	

Table 14: Summary of heavy metal removal capacity of the six-wetland plant species during 14th days period.

Heavy metal	Initial Conc.	Low	Density of plants Medium	High
Fe	Low		<i>Pistia stratiotes</i>	<i>Pistia stratiotes</i> *
			<i>Limnocharis flava</i>	<i>Eichhornia crassipes</i> <i>Jussiaea repens</i> <i>Ipomoea aquatica</i> <i>Limnocharis flava</i>
			<i>Limnocharis flava</i>	<i>Limnocharis flava</i>
Medium			<i>Pistia stratiotes</i>	<i>Pistia stratiotes</i> *
			<i>Limnocharis flava</i>	<i>Ipomoea aquatica</i>
			<i>Limnocharis flava</i>	<i>Limnocharis flava</i>

	High		<i>Pistia stratiotes</i>	<i>Pistia stratiotes</i>
			<i>Limnocharis flava</i>	<i>Jussiaea repense</i>
				<i>Limnocharis flava</i>
Cd	Low		<i>Salvinia molestra</i>	<i>Limnocharis flava</i>
	Medium	<i>Limnocharis flava</i>	<i>Ipomoea aquatica</i> <i>Limnocharis flava</i>	<i>Limnocharis flava</i>
	High		<i>Limnocharis flava</i>	<i>Pistia stratiotes</i> <i>Eichhornia crassipes</i> <i>Limnocharis flava.</i>
Cr	Low	<i>Salvinia molesta *</i> <i>Ipomoea aquatica</i>	<i>Salvinia molesta</i>	<i>Salvinia molesta</i>
	Medium		<i>Ipomoea aquatica</i> <i>Salvinia molestra</i> <i>Ipomoea aquatica</i>	<i>Salvinia molestra</i>
	High	<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica*</i>	<i>Salvinia molesta</i> <i>Jussiaea repense</i> <i>Ipomoea aquatica*</i> <i>Limnocharis flava</i>

Table cont.....

Heavy metal	Initial Conc.	Density of plants		
		Low	Medium	High
Cu	Low	<i>Salvinia molesta</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta*</i>
	Medium	<i>Salvinia molesta</i> <i>Eichhornia crassipes.</i> <i>Ipomoea aquatica</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i> <i>Ipomoea aquatica</i>	<i>Salvinia molesta</i> <i>Jussiaea repense</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes.</i> <i>Limnocharis flava</i>
	High	<i>Salvinia molesta</i> <i>Eichhornia crassipes.</i> <i>Jussiaea repense</i> <i>Ipomoea aquatica</i> <i>Limnocharis flava</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes</i> <i>Limnocharis flava</i> <i>Ipomoea aquatica</i>	<i>Salvinia molesta</i> <i>Jussiaea repense</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes *</i> <i>Limnocharis flava</i>
	Low	<i>Eichhornia crassipes.</i> <i>Limnocharis flava</i>		

	Medium	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes</i>	<i>Ipomoea aquatica</i>
	High		<i>Salvinia molesta</i> <i>Pistia stratiotes</i>	<i>Limnocharis flava</i> <i>Salvinia molesta</i> <i>Pistia stratiotes</i> <i>Eichhornia crassipes.*</i>
			<i>Eichhornia crassipes</i> <i>Limnocharis flava</i> <i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i> <i>Limnocharis flava</i>
Ni	Low	<i>Jussiaea repense</i>	<i>Salvinia molesta</i> <i>Pistia stratiotes</i> <i>Eichhornia crassipes</i> <i>Limnocharis flava</i> <i>Ipomoea aquatica</i> <i>Jussiaea repense*</i>	<i>Salvinia molesta</i> <i>Jussiaea repense</i> <i>Ipomoea aquatica</i> <i>Limnocharis flava</i> <i>Eichhornia crassipes</i>
	Medium	<i>Jussiaea repense</i>	<i>Jussiaea repense</i>	
	High	<i>Jussiaea repense</i>	<i>Eichhornia crassipes</i> <i>Jussiaea repense</i>	<i>Eichhornia crassipes</i> <i>Jussiaea repense</i>
Pb	Low		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i> <i>Jussiaea repense</i>
	Medium			<i>Ecchornia crassipes</i> <i>Ipomoea aquatica</i>
	High		<i>Ipomoea aquatica</i>	<i>Ipomoea aquatica</i> <i>Eichhornia crassipes</i> <i>Jussiaea repense</i> <i>Limnocharis flava</i>
Zn	Low	<i>Salvinia molesta</i> <i>Eichhornia crassipes *</i>	<i>Eichhornia crassipes.</i> <i>Ipomoea aquatica</i>	<i>Eichhornia crassipes.</i> <i>Ipomoea aquatica</i>
	Medium	<i>Salvinia molesta</i> <i>Eichhornia crassipes *</i> <i>Ipomoea aquatica</i> <i>Limnocharis flava</i>	<i>Eichhornia crassipes.</i>	<i>Eichhornia crassipes.</i>
	High	<i>Salvinia molesta</i> <i>Eichhornia crassipes.</i>	<i>Salvinia molesta</i> <i>Eichhornia crassipes.*</i> <i>Ipomoea aquatica</i>	<i>Salvinia molesta</i> <i>Ipomoea aquatica</i> <i>Eichhornia crassipes *</i> <i>Limnocharis flava</i>

iv) Discussion

1. Characterization of the wetland with respect to pollution abatement function

Analyses made on the data obtained from water and sediment of Iriyawetiya wetland with respect to turbidity (sediment) N,P,K and metal (Al, Fe, Cd, Cr, Cu, Mn, Ni, Pb and Zn) contents reveal that the wetland loading of above pollutants is reduced from the inlets to the outlet. Turbidity created by sediment in the inflow to the wetland is removed over 99% when it reaches the outlet. Low flow rates within the wetland that has resulted by the impoundments across the middle part of it that has created a pool of water with extremely low flow rate and thus a longer retention time (water leaves the middle part through a few culverts made across the roads) has allowed sediment to be settled on the wetland bed. Besides, presence of high density of plants in the peripheral areas may further reduce the flow rates allowing sedimentation.

Removal of nitrogenous nutrients was less than 50%, indicating low efficiency of the wetland in removing N-nutrients. Nitrogenous nutrients are removed in wetlands through accumulation by plants and microorganisms, sedimentation, denitrification and ammonia volatilization (Mitsch *et al.*, 2000). Out of these mechanisms, only denitrification and ammonia volatilization actually eliminate nutrients from the system by releasing nitrogen to the atmosphere. The other two only immobilize and detain nutrients. Nutrients accumulated by plants are temporarily immobilized, after which, they may be re-mobilized or accumulated in the sediment, where they remain immobilized for an indefinite period in an adsorbed or particulate form. Denitrification, which has not been investigated in the present study, is brought about by anaerobic bacteria and it is the primary mechanism for nitrogen removal from wetland waters into the atmosphere (Sather and Smith, 1984). The denitrification rate varies according to temperature, pH, organic carbon availability, and available surface area. The aerobic rhizosphere that surrounds wetland plant roots, maximizes the aerobic/anaerobic interface where denitrification can occur (Hemond and Benoit, 1988) Denitrification may be enhanced further in wetlands which are alternately wet (anaerobic) and dry (aerobic). High levels of nitrogen loss have been shown to occur under such conditions (Patrick and Wyatt, 1964; Macrae *et al.* 1968; Reddy and Patrick, 1984). Since Iriyawetiya wetland receives water from the inlets throughout the year from its catchment and that the flow rates are low, this wetland has never been observed to run dry during the study period. The low efficiency associated with nitrogen removal may thus be largely attributed to low occurrence of denitrification in the wetland.

Nitrogen and phosphorus may also be removed through uptake by vascular plants and subsequent "burial" when the plants die and organic matter accumulates in the sediments. DeLaune *et al.* (1986) showed that in a freshwater marsh, a large proportion of the nitrogen is incorporated in vegetation where it accumulates mainly as organic nitrogen. Once the plants die they get added to the sediment pool of nitrogen, nevertheless in an immobilized state until it is being mineralized by microbial action and become bioavailable in the aqueous medium. Removal of plants from Iriyawetiya wetland takes place very marginally and irregularly as the surrounding areas are too populated animal husbandry is not practiced as a livelihood by the local communities. Although there is a buffalo kraal close to the wetland animals are seldom fed with wetland vegetation. As such, it is appropriate to conclude that N taken up by the plants are temporarily retained in plant tissues and get added to the sediment with their death, increasing its total N content as shown by the results of present study. Highest total sediment nitrogen content in Iriyawetiya

wetland was observed at Inlet 1 where the total plant diversity is highest and the vegetation is dominated by *Alocasia macrorhiza* (a rooted emergent plant), justifies to some extent that N taken up by the plants are added to the sediment with their death. A substantial amount of the nutrients taken up by rooted emergent plants may be lost to the water through litter fall and subsequent leaching. However, this is often less than may be expected because, by the time the above-ground parts of higher plants die, most of the nutrients have been translocated to the below-ground storage portions of the plant where they may be "buried" in the deep sediments (Hemond and Benoit, 1988).

The results obtained in the present study therefore indicates low efficiency of removal of nitrites, nitrates and therefore total nitrogen from the water column by the wetland, thus it is a poor N-trap on contrary to the results available in published literature (Van der Valk *et al.*, 1979, Mitsch and Gosselink, 1986).

Richardson and Nichols (1985) found that wetland mineral soils had a greater phosphorus retention capacity than organic soils. Adsorption of phosphorus onto mineral sediments appears to be the most important mechanism accounting for the removal of this nutrient (Hemond and Benoit, 1988). Data obtained from Iriyawetiya wetland reveals low average total P contents in sediment when compared to that of water. Being part of Muthurajawela peat bog and had been used as a paddy field until a decade ago, it is not unreasonable to expect high soil organic matter content to occur, thus reducing the surface area available for P to get adsorbed, resulting low sediment P contents.

Phosphorus may also be removed from solution by precipitation as insoluble iron, aluminium or calcium phosphate or through deposition of suspended sediment to which phosphorus is already adsorbed (Nichols, 1983). Thus, the ability of a wetland to retain phosphorus through adsorption and precipitation is related strongly to its capacity to trap mineral soils (Hemond and Benoit, 1988) as well as to the particle size distribution of the trapped sediment, which affects the total surface area available for adsorption.

Available and total P contents both in water and sediment however have shown a reduction across the wetland, i.e. phosphorus is retained within the wetland thus acting as a P-trap or a sink.

Van der Valk *et al.* (1979) attribute the differences among wetlands in their nutrient-trapping capacity to be primarily the result of differences in hydrology and the interaction of seasonal fluxes of nutrients within a wetland. Nitrate and nitrite contents in Iriyawetiya wetland waters did not show a significant variation among different sites of the wetland, indicating that apart from the point-sources of nitrogen containing effluent that reaches the wetland through inlets 1 and 2, surface runoff from the peripheral areas too bring nitrogenous nutrients to the wetland that has been indicated by the relatively high concentrations of nitrates and nitrites at the outlet.

BOD (Biological Oxygen Demand) of water is a measure of the oxygen required for the degradation of organic matter and therefore an indication of the extent of pollution caused by organic matter in water. Wetlands decrease the BOD of introduced waters through the decomposition of organic matter during aerobic bacterial respiration (Hemond and Benoit, 1988). While wetland plant material is a source of organic matter, the presence of wetland vegetation can also improve purifying capacity by trapping particulate organic matter and providing aerobic rhizosphere for breaking

down of organic matter through oxidation. Iriyawetiya wetland proved to be a very effective organic matter remover as it has shown over 90% reduction of BOD and COD (organic matter) and a 55% increase of DO when the water passes through the wetland from inlets to outlet.

Metal pollution is often primarily anthropogenic in origin, with the greatest concentrations generally being found in areas with heavy industry or mining. Although it is neither a mining area nor an area with heavy industries, the peripheral areas of Iriyawetiya wetland supports small-scale industries such as brassware manufacturing and those that involves vehicle repairing and electro-plating. Besides, major and minor motor-ways are in the vicinity of the wetland, which could be the major source of metal pollutants in the wetland.

Metal removal efficiencies of wetlands can vary greatly depending on the particular metals and wetland types involved. Giblin (1985) summarized the findings of different studies investigating the passage of metals through various types of wetlands. Measured values ranged from 0% lead passing through an English bog to 100% zinc passing through a North Carolina salt marsh. Results of the present study (Table 4.6) revealed that Iriyawetiya wetland is an effective sink for all the metals investigated for the purpose. Besides the soil-borne metals such as Al, Fe and Mn, Cr was the highest retained in the wetland as indicated by the percentage removal (55.71 ppm) of the metal from water once it passes from inlets to outlet. Correspondingly, decline in sediment Cr contents from the inlet to the outlet also was the greatest. Cd, Cu, Ni, Pb and Zn concentration in water and sediment at the outlet were significantly different from that of the inlets, indicating that this wetland functions as a trap for anthropogenic metals and thus contributes to abatement of pollution due to metals in the environment.

Metals may be removed from solution by adsorption onto suspended sediment (mineral and organic), and buried in the sediment when it settles. Metals may also be adsorbed directly onto already immobile sediment (Hemond and Benoit, 1988). The oxidation-reduction (redox) potential is a key factor influencing the retention of metals (Gambrell and Patrick, 1988). Certain metals, such as cadmium and zinc, are more strongly bound to humic material under anaerobic than under aerobic conditions. In contrast, other metals, such as iron (precipitated as ferric oxide under aerobic conditions) may be released back into wetland waters as ferrous iron with the onset of anaerobic conditions (Hemond and Benoit, 1988). The pH is another important factor influencing metal retention where low pH mobilize metals from sediment. High Fe content in water of Iriyawetiya wetland may be attributed for the above causes.

Most metals are sorbed more efficiently by organic than by mineral soils (Vestergaard, 1979). Since wetland sediments are usually rich in organic matter, they are likely to be better suited for sorption of metals than non-wetland soils with less organic matter. Some metal cations also appear to form organically bound complexes with soil organic matter; in such cases, sorption is essentially nonreversible provided the soil is not disturbed (Wieder and Lang, 1986). Being part of a peat bog, Iriyawetiya sediment may contain high proportion of organic matter that retains metals immobilized, resulting high sediment metal contents, which qualifies the wetland as an efficient sink for metal pollutants.

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Wetland plants are able to take up metals from the water and sediment. However, the degree to which this leads to the removal of metals depends on the extent to which the plant material is accumulated in organic sediment rather than being exported from the system as detritus (Hemond and Benoit, 1988).

2.Characterization of wetland macrophytes in accumulation of nutrients and heavy metals

Aquatic plants absorb elements through roots and/or shoots. Various species show different behaviour regarding their ability to accumulate elements in roots, stems and/or leaves. (Baldantoni *et al.* 2004). In aquatic systems, where pollutant inputs are discontinuous and pollutants are quickly diluted, analyses of plant tissues provide time integrated information about the quality of the system (Baldantoni *et al.* 2005). In Iriyawetiya wetland, fourteen aquatic macrophytic species have been identified and all of them were investigated for their metal accumulation capacity.

The BCF for Cd accumulation by for *E. crassipes* (622) is precisely the same as the value reported by Lu *et al* (2004) in Thailand. Nevertheless, value for Zn for the same species is far less (2) than that has been calculated (788.9) by the same researchers who have carried out the experiment in tanks using known concentrations of metal, unlike the present study where naturally occurring plants in the wetland was used for the purpose. Besides, the average Zn content in water in the wetland was relatively low and that would have contributed to low BCF of *E. crassipes* in Iriyawetiya wetland.

Nitrogen accumulation in *I. aquatica* in Iriyawetiya wetland showed a significant variation among the plants collected from inlet1 (31 mg/ g) and the outlet (24 mg/g) and it was far less than that have been recorded (53 mg/g) for the species grown in a container with effluents from a septic tank (Tanaka *et al.* 2006). For the same species in the inlet, the amount of P accumulated was 2 mg/g while it was 9.5 mg/g for the same species recorded in the previous study indicating low P levels in the wetland as confirmed with the results of the present study.

For *Monochoria vaginalis* collected from Iriyawetiya wetland, nitrogen content in the plant was 33 mg/g is comparable with the value reported (30 mg/g) for *Monochoria cyanea* by Tanaka *et al* (2006).

Nitrogen content in plant tissues showed a declining order as *A. macorrhiza* > *M. vaginalis* > *I. aquatica* > *L. flava* > *P. stratiotes* > *Alternanthera sessilis* > *C. diffusa* > *P. repens*

The BCF values calculated for the wetland plant species reveal that *A. macorrhiza* (85) can be identified as the best Fe accumulator while the floating species, *P. stratiotes* (83) *S. molesta* (73) and *E. crassipes* (60) also show hyperaccumulative capacities for Fe.

E. crassipes appears to be a hyperaccumulator for Mn (339) and Ni (5047) while *P. stratiotes* is the second best accumulator of Mn (313) and Ni (2535) and hence they can be used as biomonitors for these metals in aquatic environments.

Rooted emergent plant species recorded the highest BCF for Pb and among them *L. flava* (1821) and *I. globosa* (1817) are of the highest value, indicating their hyperaccumulation capacity of this metal pollutant and therefore a potential phytoremediation agent for managing Pb levels in the aquatic environment.

Floating species recorded the highest BCF values for Cr and Cu, and among them, *S. molesta* recorded the highest indicating its potential to be used in plant-based Cr

treatment systems. Having recorded the highest BCF for Cu (307) *P. stratiotes* proves to be a candidate phytoremediation agent for Cu containing effluents.

Except for *E. crassipes*, all the other tropical wetland plants investigated in the present study have been inadequately studied or not studied at all for their capacity for hyperaccumulation of metals and for potential as agents for biomonitoring for metal pollutants in aquatic environments.

4. Phytoremediation potential with respect to and heavy metal removal of selected wetland macrophytes

The above results revealed the relative phytoremediation capacity of the six wetland macrophyte species tested in the present study and they are discussed in detail below.

i. Phytoremediation of Fe

It is noteworthy that *P. stratiotes* showed the highest percentage removal of Fe from water in the artificial wastewater medium. Being an abundant bioavailable metal, high concentration of Fe in the waters in and around (including ground water) Iriyawetiya wetland, pollute potable water in the area. *P. stratiotes* in the hydroponic experiments showed more than 75% removal of Fe from water, thus indicating its suitability as a phytoremediating agent for Fe. *S. molesta* showed the least affinity to remove Fe in water and the other four species removed 50% after 9 days, thus manifesting an intermediate performance in removing Fe from water.

ii. Phytoremediation of Cd

In the case of Cd, it is often assumed that its uptake is unspecific and inadvertent via transporters for other essential nutrients. Effective Zn hyperaccumulators have been shown to remove Cd too (McGrath *et al*, 2002). Present study also reveals that *Eichhornia crassipes* has a medium phytoremediation capacity in removing Cd (Baker and Brooks, 1989) when compared to *S. molesta*, *I. aquatica* and *L. flava*. Being a rooted emergent, *L. flava* appears to remove Cd in sediment while the other two floating species the dissolved Cd. These three species therefore prove candidate species for a treatment system for Cd-rich effluents that are associated with vehicle repair shops in the urban environments.

iii. Phytoremediation of Cr

Members of the Brassicaceae family are evidently the most effective plants in removing Cr (Zayed *et al*, 1998a). Present study reveals the relatively high capacity of *I. aquatica* in removing Cr from the artificial wastewater where it has removed more than 50% at lowest density within 6 days and more than 75% after 9 days and also indicating its tendency to hyperaccumulation of the metal. *I. aquatica* can be used to treat tannery effluents that contain higher percentage of Cr.

iv. Phytoremediation of Cu

Blaylock *et al* (1997) express their doubt about the ability of any species to hyperaccumulate this metal and therefore the only means available is the chemical enhancement. In the present study however, Cu has been removed more than 50% from the initial concentration even as low as 1 mg/l, within 6 days by *E. crassipes* and *L. flava*, indicating their hyperaccumulative tendency for Cu. If provided an exposure time of 14 days, *S. molesata*, *E. crassipes*, *J. repense*, *I. aquatica*, *L. flava*

too are able to remove more than 50% of Cu from a low (1 mg/l) initial concentration with the least density of plants, indicating their suitability for a treatment system that can afford to have a prolonged length for the process.

v. Phytoremediation of Mn

Studies have shown that uptake of Mn, by barley (*Hordeum vulgare* var. Proctor) grown in a solution culture was stimulated by microorganisms, irrespectively of whether they originated as casual laboratory contaminants or as rhizosphere microorganisms in the soil Barber and Lee, 1974). The microbial effect is mediated by a water-soluble substance, but neither its identity nor its mode of action was established. When Mn was supplied as EDTA chelates these appeared to be broken down at or near the surface of the roots. This process was accelerated in the presence of microorganisms. This may be the reason for observing very low removal of Mn from the hydroponic medium up to 9 days, where none of the plants recorded 50% percentage removal, nevertheless, after 14 days, except for *J. repense* all other plants showed more than 50% removal at high density with highest initial concentration of the metal.

vi. Phytoremediation of Ni

J. repense has shown hyperaccumulative tendency for Ni and within 9 days it has removed more than 75% of Ni in the artificial wastewater at medium density of plants, indicating its suitability as a phytoremediating agent for the waters contaminated with Ni.

vii. Phytoremediation of Pb

Since Pb is hardly soluble in sediment/ soil, Pb hyperaccumulation is rare. Fourteen taxa have been reported to be Pb hyperaccumulators with Pb concentration in the shoots varying from 1000 - 20,000 µg/g (Reeves and Baker, 2000). Results presented in Chapter 5 shows that none of the species encountered in Iriyawetiay wetland is of that hyperaccumulative capacity. Among the tested plants in the present study, *I. aquatica* removed more than 75% of Pb in the hydroponic medium at high density, i.e. 38 plants/ m² after 6 days. *E. crassipes*, *J. repense* and *L. flava* removed 50% at high density after 6 days. Results experiments on Pb uptake by the plant *Thlaspi rotundifolium* by Huang and Cunningham (1996) using hydroponic and soil systems have indicated that this plant does not hyperaccumulate Pb in the shoots but in the roots, particularly in the apoplast, principally as lead sulphate deposits. As such, this type of Pb accumulation does not represent true uptake by plant roots.

viii. Phytoremediation of Zn

Zn is a widespread harmful heavy metal, but there is no cost-effective mean to remove them from the soil. Although phyto-extraction using hyperaccumulator plants is seen as a promising technique, a lack of understanding of the basic physiological, biochemical, and molecular mechanisms involved in heavy metal hyperaccumulation prevents the optimization of the phyto-extraction technique and its further commercial application (Cosio *et al*, 2004). The highest percentage removal of Zn was shown by *E. crassipes* by removing more than 50% at low density within 6 days of exposure to 1 mg/l concentration of Zn in the artificial wastewater, indicating its hyperaccumulation tendency for Zn. Prolonged exposure (14 days) have proved *S. molesta* and *I. aquatica* also perform their best in removing Zn. All three plants are floating (a good part of *I. aquatica* is also floating) and it is not difficult to understand that high solubility of Zn allows these plants to be the best removers of this metal from water.

Wetland plants tested in the present study revealed that their phytoremediation capacity for metals in water varies considerably. Results of the current study therefore reveal that hydroponically grown wetland plants may be used to treat waste water with varying composition of metal pollutants and thus support the hypothesis that hydroponically grown wetland macrophytes can be used to treat wastewater in small-scale operations.

v) Conclusions

i. Pollution abatement function of Iriyawetiya wetland

Performance of Iriyawetiya wetland in removing nutrients and heavy metals is high and therefore it can be utilized for abatement of pollution caused by storm water and sewage from populous Kiribathgoda peri-urban area, through appropriate ecological engineering methods.

ii. Characterization of wetland macrophytes in accumulation of nutrient and heavy metals

Wetland plant species that have been investigated during the present study showed varying capacities of removing heavy metals from water and sediment under natural conditions and some species hyperaccumulated certain heavy metals manifesting their high potential as phytoremediation agents for abatement of pollution by nutrients and heavy metals.

iii. Phytoremediation potential with respect to and heavy metal removal of selected wetland macrophytes

In order to harness the phytoremediation capacity of wetland plants they have to be used in optimal densities and durations.

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vii) Problems if any, encountered during the implementation of the project

Delay in releasing funds for initial purchases

Although the official date of commencement of the project was 01.02.2002, work could not be commenced then as the initial release of funds was delayed. Once the delay was communicated to the investigators, they had to make other arrangements to secure funds to purchase chemicals to start the work. For the first year, only the stipend of the research assistant was paid from the project funds.

Delays due to unavailability of AAS

The AAS available at the Department of Chemistry, University of Kelaniya was out of order for a number of months in two occasions during the project period and that caused a considerable delay in completing the analytical work.

Section 4

Impact of Research results

i) Relevance of results achieved to scientific advancement

Wetlands in general are considered wastelands as they are reckoned useless unless reclaimed and utilized for other uses such as agriculture, industry, human settlements and urban areas. Research to reveal their ecological functions are scanty and it is particularly true for tropical wetlands where the associated biodiversity is high. Knowledge on wetland functions will elucidate the ecological value of these ecosystems and thus will lead to their wise use rather than allowing these ecological services to be lost forever.

The present study therefore contributes to generate knowledge on the following aspects relevant to tropical wetlands.

1. Capacity of wetlands to remove sediment, nutrients and heavy metals and the relative proportion of these pollutants abated by the wetland
2. Role of tropical wetland plants in removing nutrients and heavy metals from water and sediment
3. Rates of removal of eight heavy metals by six tropical wetland plant species, representing floating, submerged and rooted aquatic plants and thus their potential to be exploited as phytoremediation agents for removing those metals from domestic and industrial waste water.

ii) Relevance of results achieved to national/socio-economic development

1. Aquatic pollution, particularly in urban environments, is an environmental issue in Sri Lanka that has hardly been attempted to solve as the environmental engineering methods in common practices are prohibitively expensive. Ecological engineering methods that use whole ecosystems therefore provide an economical alternative, particularly to nations such as Sri Lanka where finances available for pollution abatement is scarce. The baseline that this study established on the capacity of a freshwater wetland in performing the task of abating pollution due to nutrients and eight heavy metals provides authenticated foundation to use wetland-based ecological engineering methods as a solution to check inland aquatic pollution.

2. The functional capacity of wetlands can also be used by wetland conservationists to justify their activities and to add value to otherwise of poorly valued wetlands in Sri Lanka, thus saving the wetlands along with other wetland functions such as ground water recharge, biomass production, provision of habitats for wildlife.

3. Identification of wetland plants that are able to hyperaccumulate the most commonly found heavy metal in the environment can be harnessed to develop plant-based secondary and tertiary waste water treatment systems for industrial effluents and domestic as well as hotel sewage. Sewage disposal by the large and medium-scale hotels in the south-western coastal belt of Sri Lanka where the water table occurs near the ground surface, is an environmental issue that has hitherto not been addressed adequately. Phytoremediation capacity of plants, particularly in relation to

removal of nutrients from water/ wastewater and thus to check eutrophication of natural waters into which wastewater is discharged without control can be harnessed through development of appropriate treatment systems and using natural and/or artificial wetlands.

iii) Dissemination/application of research output

Dissemination of the findings of the present study has already been done through presentations in local and international scientific forums and research papers are in preparation to be published in local and international scientific journals.

Section 5

Miscellaneous

- i) List of major equipment acquired during the project period and their functionality

No equipment was acquired during the project period with project funds.

- ii) List of publications/communications arising from the project and/or presentations made at seminars, workshops etc. (Please attach copies)

K G S Nirbadha, M D Amarasinghe and J A Liyanage, '*Sri Lankan aquatic plants with a potential for phytoremediation of Pb*', International Forestry and Environmental Symposium, November 2007, 12, 44.

Nirbadha, K G S, Liyanage, J A and Amarasinghe, M D, '*Heavy Metals in Substrate of a Freshwater wetland at Kelaniya*', International Forestry and Environmental Symposium, December, 2006, 11, 31.

Nirbadha, K. G. S., Amarasinghe, M. D. and Liyanage, J. A., '*Phytoremediation potential of Iriyawetiya wetland at Kelaniya for heavy metal contaminated urban runoff*', Proceedings of the Sri Lanka Association for the Advancement of Science, 2004, 60, 186.

Amarasinghe, M. D., Nirbadha, K. G. S. and Liyanage, J. A., '*Presence of Heavy Metals in Plants of a Tropical Wetland in Sri Lanka as an Indicator of their relative Phytoremediation potential for Heavy Metal Contaminated Water from Urban Runoff*', 2nd Bangi World Conference on Environmental Management, Malaysia, 2004

Nirbadha, K. G. S., Liyanage, J. A. and Amarasinghe, M. D., '*A Preliminary Study on the Presence of Heavy Metals in Aquatic Plants from a fresh water wetland at Kelaniya*', Proceedings of the Ninth Annual Forestry and Environment Symposium, University of Sri Jayewardenepura, 2004.

Nirbadha, K. G. S., Amarasinghe, M. D. and Liyanage, J. A., '*A preliminary study on the heavy metal contents of two common fresh water Marsh plants Pistia stratiotes and Limnocharis flava in Iriyawetiya wetland in Kelaniya*', Proceedings of the Sri Lanka Association for the Advancement of Science, 2003, 59(I), 170.

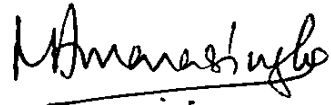
Section 6

Summary Statement of Expenditure (indicate under Personnel, Equipment, Consumables, Travel and Subsistence and Miscellaneous)

Type of expenditure	Amount (Rs)
Personnel	
Stipend of the research assistant	Rs. 505,000.00
Equipment	-
Consumables	
Consumables	Rs. 125,875.00
Traveling	Rs. 1,125.00
Miscellaneous	-
Total expenditure	Rs. 632,000.00

Section 7

i) Grantees' signatures



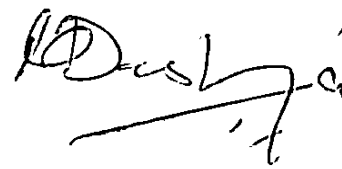
Dr (Mrs) M.D. Amarasinghe



Dr (Mrs) J.A. Liyanage

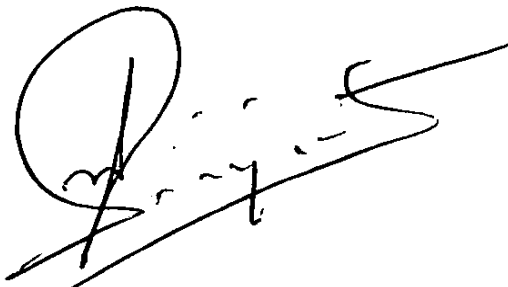
ii) Comments of the Head of the Department/signature

Mr KGS Nirbadha, RA to this project has completed the necessary work and submitted the thesis for an MPhil degree.



Head. Department.
University of Kelaniya

iii) Head of the Institution's signature



Prof. M.J.S. Wijeyaratne
Vice Chancellor
University of Kelaniya

Professor MJS Wijeyaratne
Vice-Chancellor
University of Kelaniya
Kelaniya-Sri Lanka

PRESENCE OF HEAVY METALS IN PLANTS OF A TROPICAL WETLAND IN SRI LANKA AS AN INDICATOR OF THEIR RELATIVE PHYTOREMEDIATION POTENTIAL FOR HEAVY METAL CONTAMINATED WATER FROM URBAN RUNOFF

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ABSTRACT

Aquatic plants are known for their ability to absorb heavy metals from water and sediment and the amount absorbed and retained by plants depends on nature of the plant and the availability of heavy metals in the environment. Nine species of herbaceous plants, i.e. *Alternanthera sessilis*, *Commelina diffusa*, *Ipomoea aquatica*, *Jussia repens*, *Isachne globosa* (rooted plants with floating stems), *Alocasia* sp., *Limnocharis flava*, *Monochoria vaginalis* (rooted plant) and *Pistia stratiotes* (floating plant), collected from a tropical wetland in the Western Province of Sri Lanka have been analyzed for the content of lead (Pb), cadmium (Cd), copper (Cu), manganese (Mn), nickel (Ni), iron (Fe), chromium (Cr), tin (Sn) and zinc (Zn) in the plant tissues as an indicator characteristic of their ability to absorb and retain these heavy metals. Samples have been collected in replicates from the inlet, outlet and the middle section of the wetland and the heavy metal contents in roots and shoots were determined. Occurrence of heavy metals in roots was more than that in the shoots. Tin, chromium and iron were the metals found in highest abundance in all the plant species, indicating their greater presence in this wetland. Except for Fe and Zn, *Isachne globosa*, the most abundant grass in this wetland, records relatively high contents of the other six metals under study, particularly Cd and Pb, which occurs in low quantities in the other plant species. Plants that have unattached roots (in the water column), i.e. *Pistia stratiotes*, *Ipomoea aquatica*, *Alternanthera sessilis*, *Isachne globosa*, *Commelina diffusa* and *Jussia repens* record relatively higher amounts of Sn (60.855 - 105.54 g/kg), Cr (3.41-8.98 g/kg), Cu (0.23 -0.4 g/kg), Zn (0.37- 0.17 g/kg), Ni (0.18-0.39 g/kg), Pb (0.06- 0.173 g/kg), Cd (0.022-0.328 g/kg) in their roots. Rooted plants absorb and retain relatively high amounts of Fe, *Monochoria vaginalis* (40.192 g/kg) *Limnocharis flava* (77.824 g/kg) and *Alocasia* sp. (23.459 g/kg) in their roots, indicating the presence of greater loads of Fe in the sediment than in the water column. *Ipomoea aquatica* and *Alternanthera sessilis* are consumed as vegetables by the local communities. Results of the present study indicate that shoots of *A. sessilis* retains comparatively high amounts of Cd (0.7117 mg/kg), Mn (134.947 mg/kg), Sn (28876.1 mg/kg), Cr (1039.041 mg/kg), Cu (144.8043 mg/kg), Zn (118.4126 mg/kg), Pb (29.8699 mg/kg) Ni (63.473 mg/kg) and Fe (2972.8 mg/kg), which demands more attention with respect to its impact on human health.

INTRODUCTION

Phytoremediation is an emerging economical and environmentally friendly environmental technology for restoring polluted soils, ground and surface water. Phytoremediation is the use of plants to remove pollutants such as heavy metals, excess nutrients (in water), organic matter and radioactive contaminants from water or soil (Salt et al. 1995). Wetland plants are widely reputed for their heavy metal and nutrient removal ability and thus are used to treat wastewater, both industrial and sewage. Passive uptake through micro-pores in the root cell walls (apoplastic pathway) may be a major route of contaminants into the root, where sequestration or degradation can take place (Negri & Hinchman 1996). Rhizosphere microorganisms that are nourished with root exudates are partly responsible for removing pollutants from soil and water.

Iriyawetiya is a freshwater wetland situated in the wet zone and receives storm water and sewage from the nearby township. Besides, small-scale agricultural, animal rearing and small scale metal-based industries and automobile repair shops

MATERIALS AND METHODS

Nine species of herbaceous plants, i.e. *Alternanthera sessilis*, *Commelina diffusa*, *Ipomea aquatica*, *Jussia repens*, *Isachne globosa* (rooted plants with floating stems), *Alocasia sp.*, *Limnocharis flava*, *Monochoria vaginalis* (rooted plants) and *Pistia stratiotes* (floating plants) collected from a freshwater wetland, i.e. Iriyawetiya wetland, situated in the wet zone of Sri Lanka were analysed for nine heavy metals, i.e. Chromium (Cr), Cadmium (Cd), Copper (Cu), lead (Pb), iron (Fe), manganese (Mn), nickel (Ni), tin (Sn) and zinc (Zn). Plant samples were obtained in replicates from the inlet, outlet and the middle segment of the wetland and washed with de-ionized water and separated into shoots and roots. These samples were dried to constant weight at 60 °C and ground to a powder and digested completely with a mixture of Conc. Nitric, sulphuric and perchloric acid (4:1:1). Digested samples of roots and shoots were then analysed for the above heavy metals using an atomic absorption spectrophotometer.

RESULTS

Contents of Cr, Cd, Cu, Pb, Fe, Mn, Ni, Sn and Zn in one kg (dry weight) of roots and shoots of the nine wetland plant species are presented graphically in Figures 1 - 3. Iron is the most prevalent metal encountered in all the plant species while Sn and Cr too were found to occur in relatively high amounts in all the plants, indicating high concentration of these metals in Iriyawetiya wetland (sediment and water). The least found heavy metal in all nine species was Cd while Ni, Cu, Mn and Zn were present in amounts less than 500 mg/kg. Figures 4-12 depict the proportional presence of the nine metals in the roots and shoots of the nine species of plants. Fe, Sn and Cr content in the roots of all nine species is greater than that of the shoots (Figures 4, 5, & 6). Ni and Pb content in shoots of *Limnocharis flava* is higher than that of the roots (Figures 7 & 11) while Mn content in *Monochoria vaginalis* shoots also is higher than that of the roots (Figure 9). Shoots of *Commelina diffusa* retain Mn and Zn in greater amounts than the roots (Figures 9 & 10).

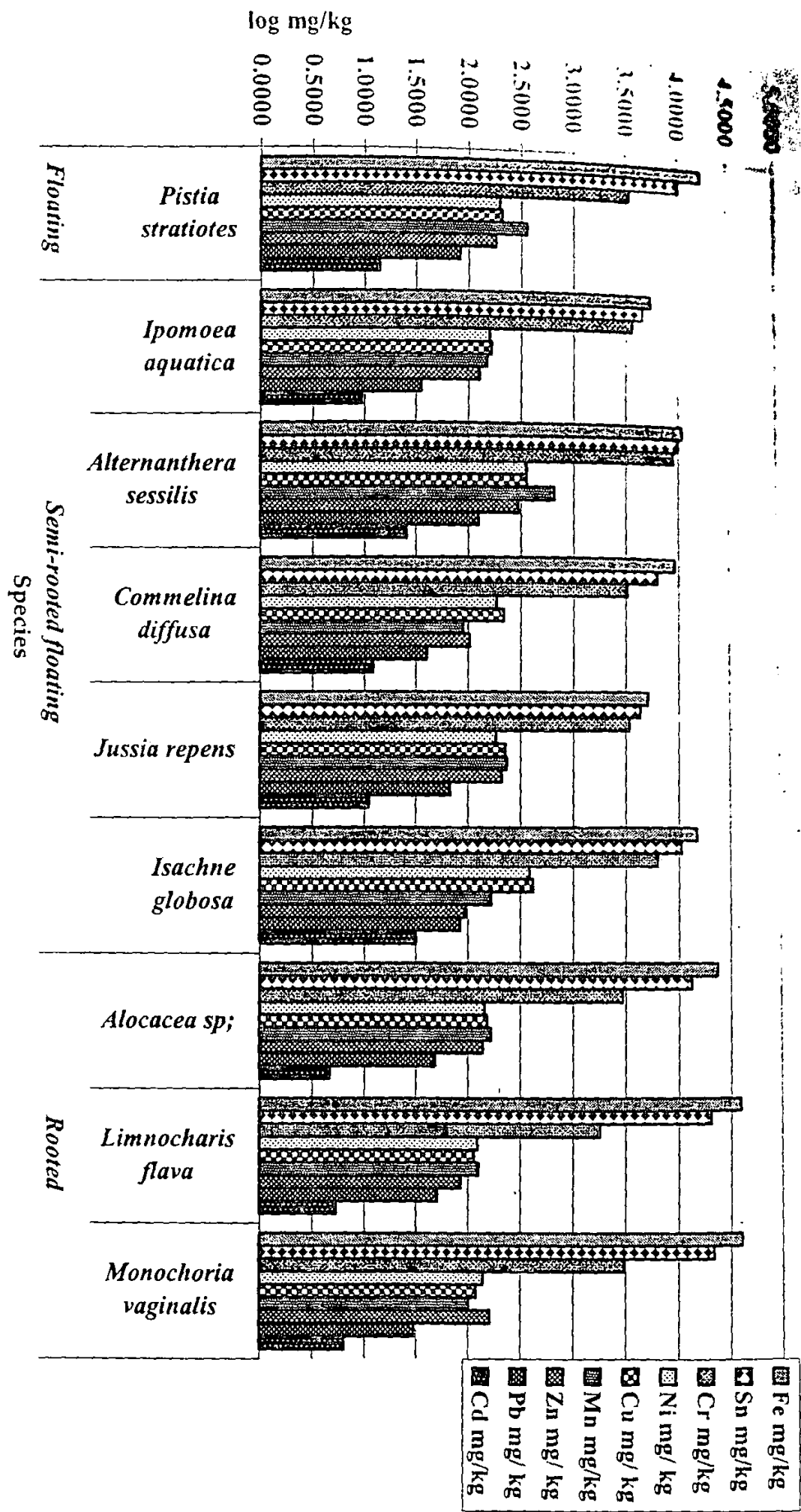


Figure 1. Occurrence of nine heavy metals in the roots of nine plant species collected from Iriyawetiya wetland, Sri Lanka

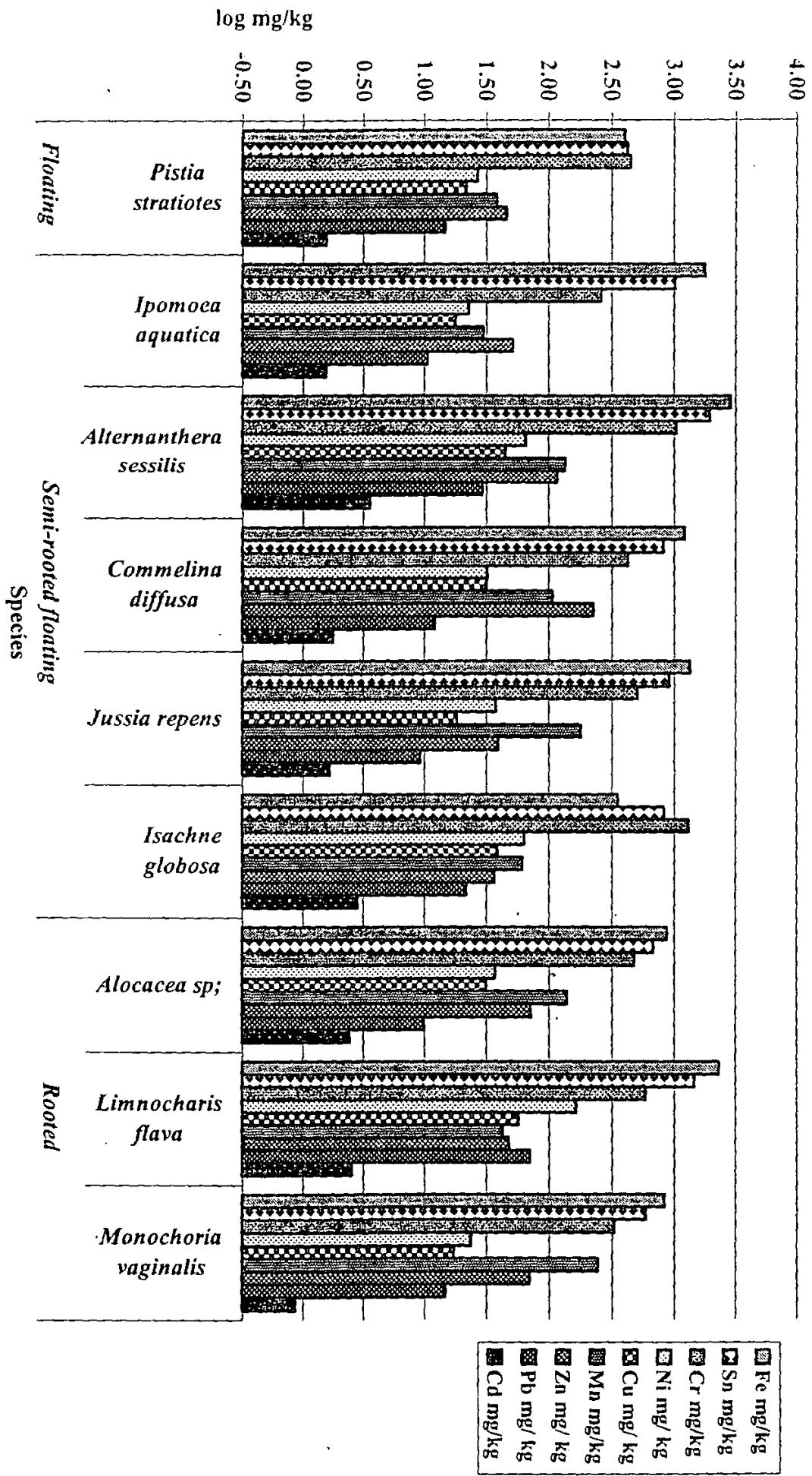


Figure 2. Occurrence of nine heavy metals in the shoot of nine plant species collected from Iriyawetiya wetland, Sri Lanka.

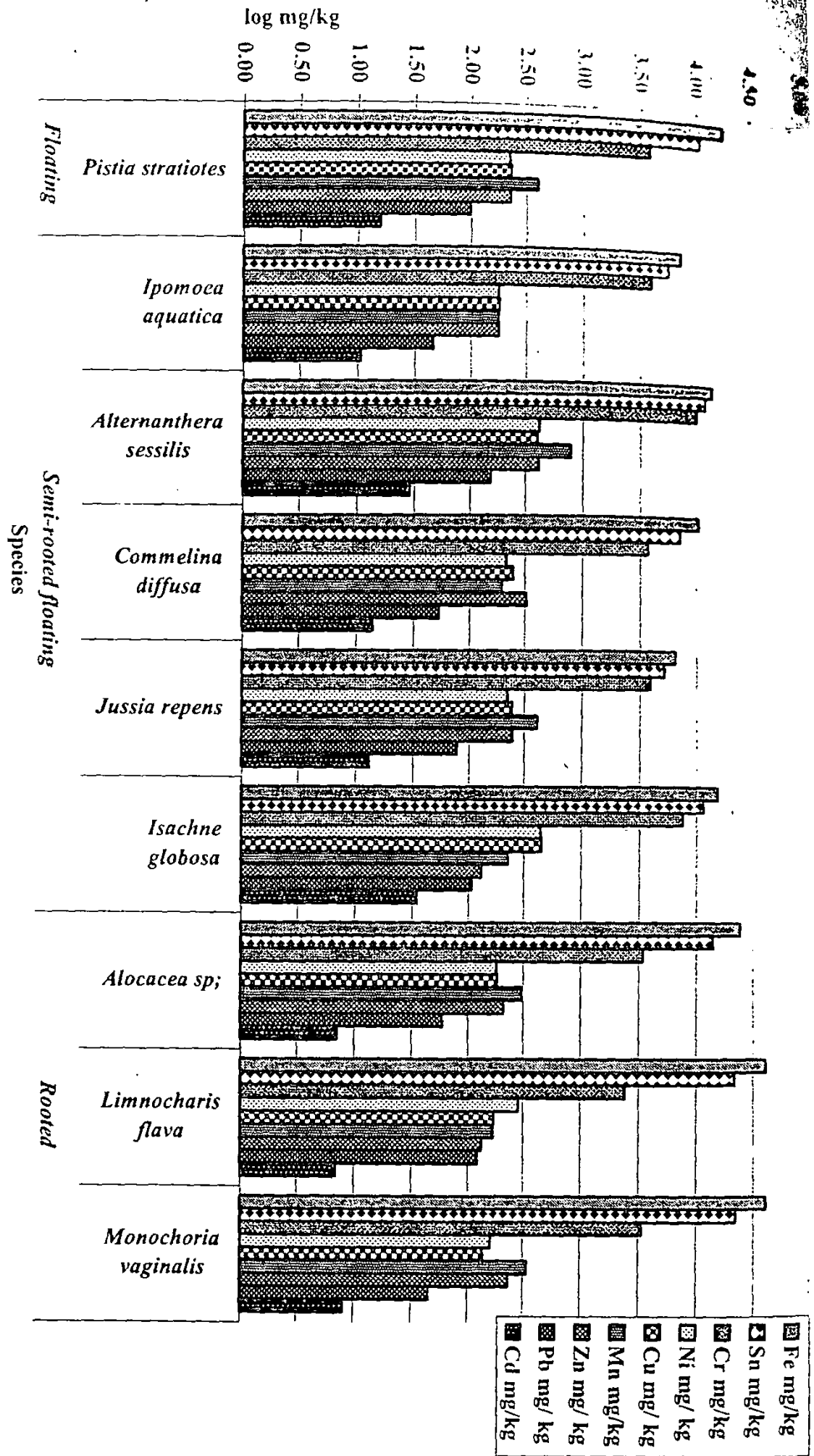


Figure 3. Total content of heavy metal of nine species collected from Iriyawetiya wetland, Sri Lanka

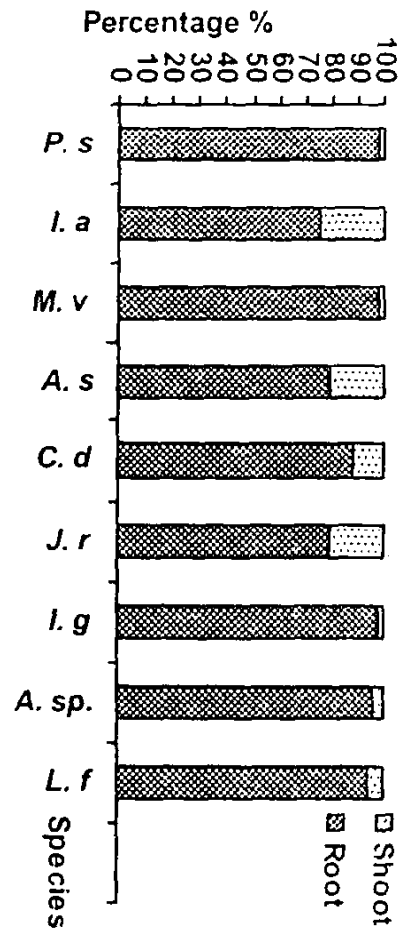


Fig. 4 : proportionate occurrence of iron (Fe) in roots and shoots of the nine plant species

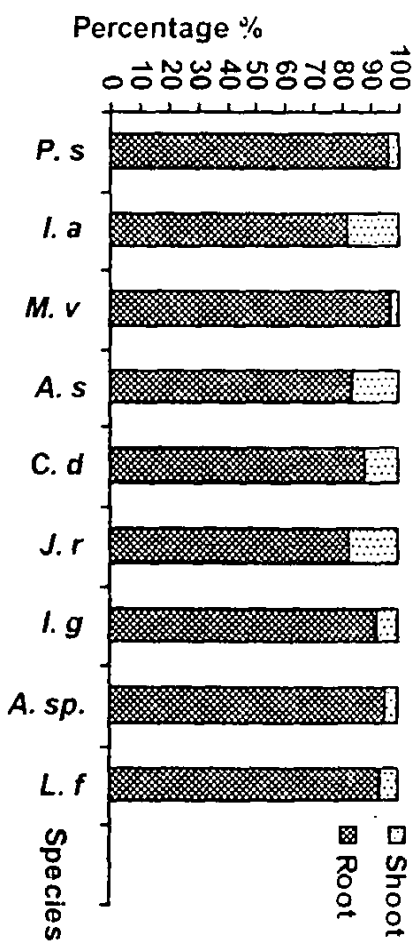


Fig. 5 : proportionate occurrence of tin (Sn) in roots and shoots of the nine plant species

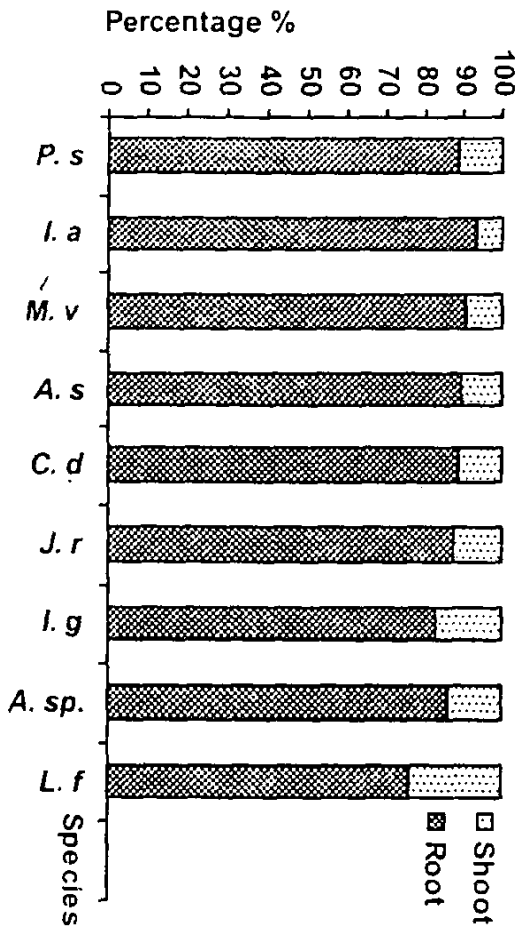


Fig. 6 : proportionate occurrence of chromium (Cr) in roots and shoots of the nine plant species

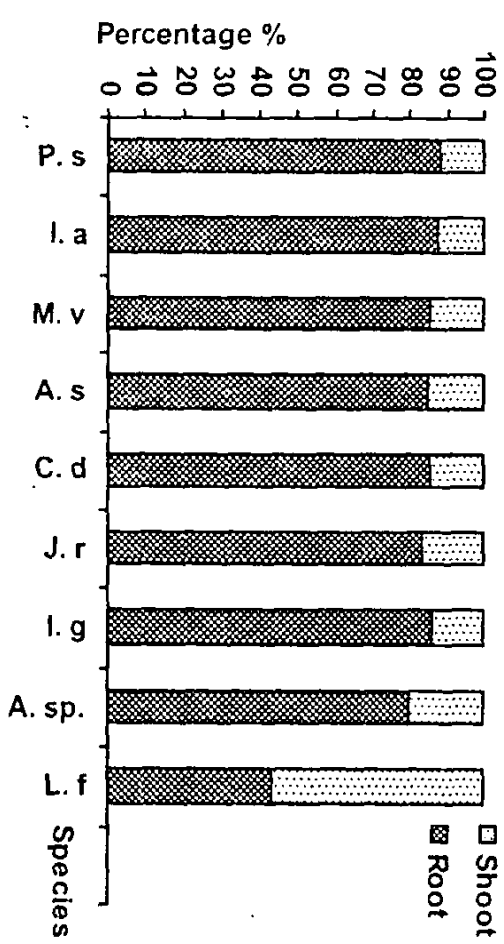


Fig. 7 : proportionate occurrence of nickel (Ni) in roots and shoots of the nine plant species

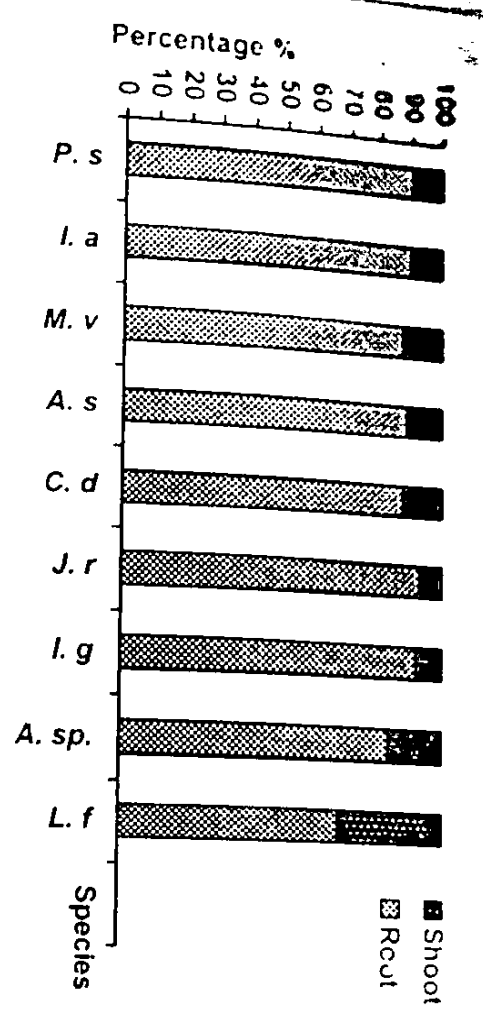


Fig. 8 : proportionate occurrence of copper (Cu) in roots and shoots of the nine plant species

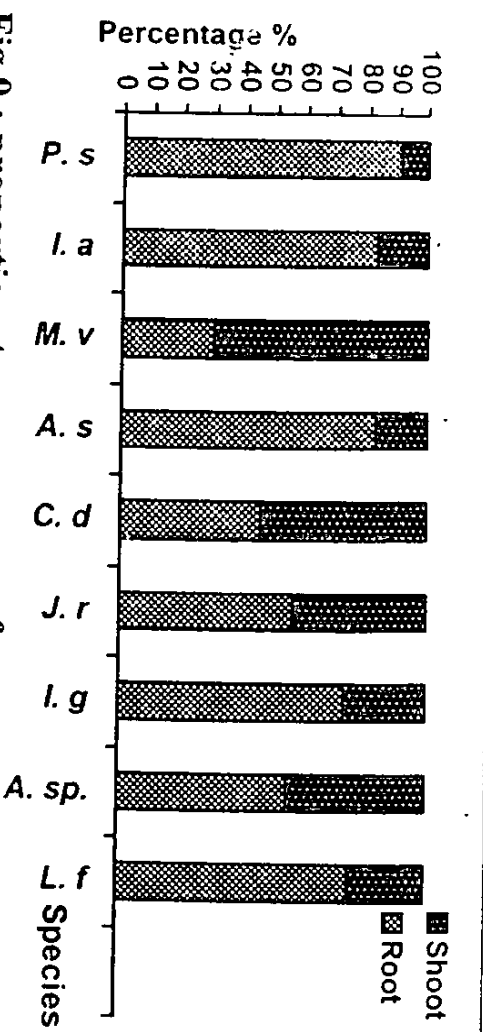


Fig. 9 : proportionate occurrence of manganese (Mn) in roots and shoots of the nine plant species

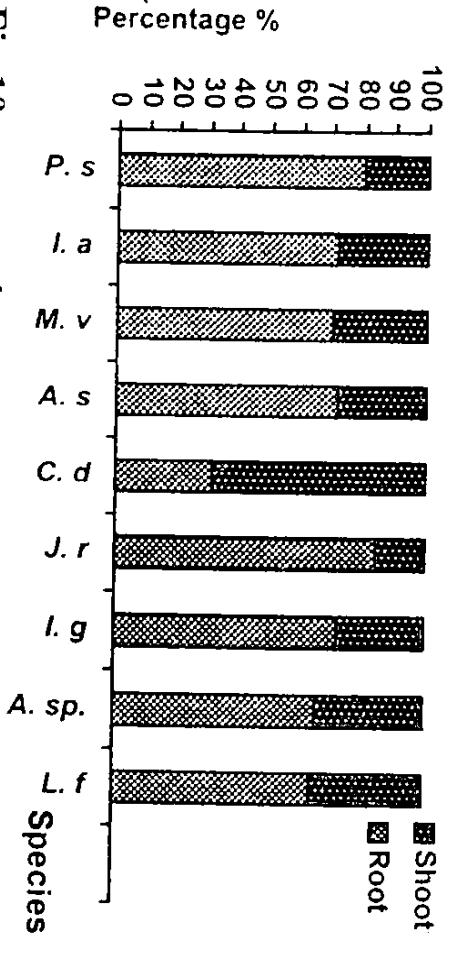


Fig.10 : proportionate occurrence of zinc (Zn) in roots and shoots of the nine plant species

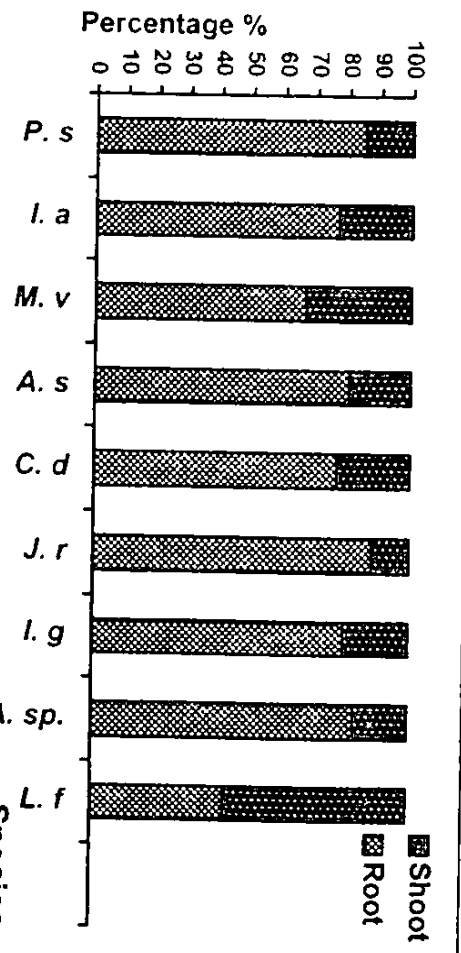


Fig.11 : proportionate occurrence of lead (Pb) in roots and shoots of the nine plant species

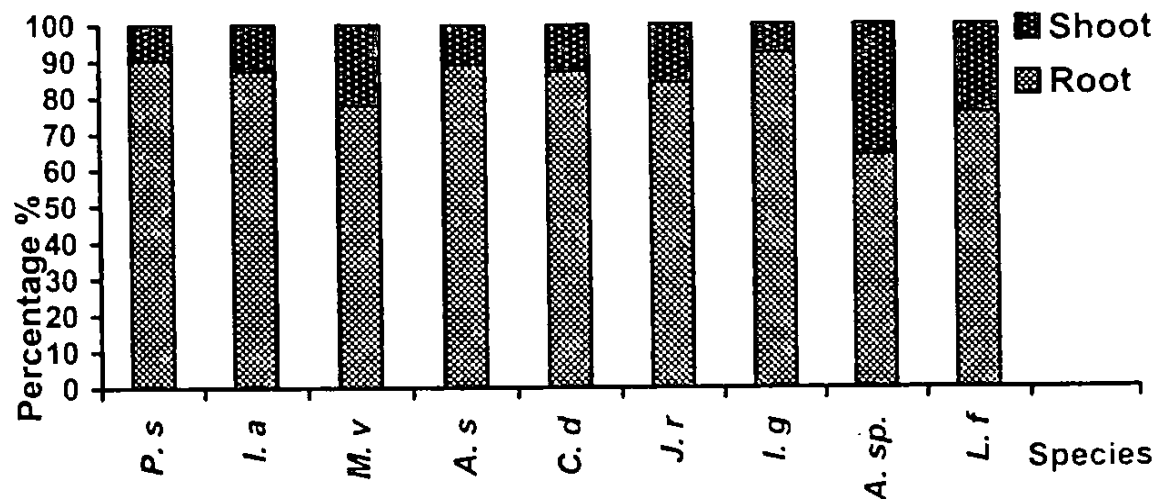


Figure 12. Proportionate occurrence of cadmium (Cd) in roots and shoots of the nine plant species

Table 1 presents the relative occurrence of the nine heavy metals in the plant species under study.

Table 1. Relative occurrence of heavy metals in the nine wetland plant species

Species	Relative occurrence of heavy metals								
	Fe	Sn	Cr	Ni	Cu	Mn	Zn	Pb	Cd
Floating plants									
<i>Pistia stratiotes</i>	+++	+++	++	++	++	++	++	++	++
Rooted plants with floating stems									
<i>Ipomoea aquatica</i>	+	+	+	+	+	+	++	+	+
<i>Alternanthera sessilis</i>	++	+++	+++	+++	+++	++++	++++	++++	+++
<i>Commelina diffusa</i>	++	+	+	++	++	+	+++	+	++
<i>Jussia repens</i>	+	+	+	++	++	+++	++	+	++
<i>Isachne globosa</i>	+++	++	++	+++	+++	+	+	+++	+++
Rooted plants									
<i>Monochoria vaginalis</i>	++++	++++	++	+	+	++	++	+	+
<i>Alocacea sp.</i>	+++	++	++	+	+	++	++	+	+
<i>Limnocharis flava</i>	++++	++++	++	++	+	+	+	+++	+

DISCUSSION

Relatively higher occurrence of Fe and Sn in all the plant species investigated indicates their high relative abundance in the wetland sediment and water. Lead and cadmium are the least found metals in the plant tissues and this may be due either to low occurrence of this metal in the wetland or the plants' inability to absorb and retain them.

Fe, Sn and Cr content in the roots of all nine species is greater than that of the shoots and it confirms previous observations. In addition to movement of metal ions into root tissues, rhizosphere microorganisms too contribute to deposition of metal ions in water. Root exudates which contain natural chelating agents such as citric, acetic and other organic acids, provide enhanced mobility to metal and other nutrient ions in water, thus facilitating their deposition. Besides, root exudates support rhizosphere microbial growth (Salt et al. 1995, Forstner & Wittman 1981). On the contrary, Ni and Pb content in shoots of *Limnocharis flava* is higher than that of the roots while Mn content in *Monochoria vaginalis* shoots also is higher than that of the roots. This is a favourable character of a candidate species, as removal of aerial parts (containing metals) is more convenient than uprooting the plant.

Alternanthera sessilis retains all the heavy metals (under study) in relatively high quantities, indicating its hyperaccumulative capacity. Except for Mn and Zn *Isachne globosa* also absorbs and retains other metals in relatively high quantities. Both these plants grow attached to the sediment and produce floating runners with new shoots and roots, which may increase the potential of absorption and retention. Furthermore, *Pistia stratiotes* also retains all nine metals in comparatively high concentrations. Being a floating plant, this species may be used conveniently to remove metals from industrial effluents. Among the rooted plants, *Limnocharis flava* proves an effective candidate species for removal of Fe, Sn and Pb.

P. stratiotes, *A. sessilis*, *I. globosa*, *M. vaginalis*, *Alocaceae sp* and *Limnocharis flava* appear to be effective candidate species to remove Fe, Sn and Cr from water and sediment. Since *A. sessilis*, *C. diffusa*, *J. repens* and *I. globosa* record relatively high amounts of Ni, Cu, Mn and Cd in the root and shoot tissues, they may potentially be used as candidate species for cleaning up water and sediment polluted with these metals. All nine species investigated under present study show wide distribution in the freshwater wetlands in the wet zone of Sri Lanka. Except for *Ipomoea aquatica* and *A. sessilis* that are used popularly as vegetables in Sri Lanka, the rest is not used for human consumption. Although low concentrations of metals occur in *I. aquatica*, *A. sessilis* is a hyperaccumulator, indicating the potential health hazards associated with its consumption. Further confirmation of bioremediation potential of wetland plant species is underway through laboratory experiments. Being a developing country in the tropics, use of wetland plants for pollution abatement is an appropriate biotechnology that has a great potential for aquatic environmental management in Sri Lanka.

ACKNOWLEDGEMENT

Authors gratefully acknowledge the financial support extended by the National Science Foundation of Sri Lanka and the laboratory facilities provided by the Departments of Botany and Chemistry of University of Kelaniya, Sri Lanka.

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Sri Lankan aquatic plants with a potential for phytoremediation of Pb

K.G.S. Nirbadha, M.D. Amarasinghe and J.A. Liyanage

Department of Botany, Department of Chemistry, University of Kelaniya

Plants have the ability to accumulate non-essential metals such as cadmium (Cd) and lead (Pb) and this ability could be harnessed to remove these pollutants from the environment. Ability of large aquatic plants (macrophytes) in purifying wastewater through removing metal pollutants has only recently been scientifically investigated and knowledge available on this ability of Sri Lankan aquatic plants is scanty.

Lead is considered a major anthropogenic heavy metal that contributes to aquatic pollution particularly through urban runoff. The bioaccumulation of lead (Pb) in aquatic plant species collected from Iriyawetiya freshwater

wetland situated in the vicinity of Kiribathgoda urban area revealed that the rooted plants are the best Pb accumulators, having recorded bioconcentration factor (BCF) values, *Alocasea macorrhiza* (1279), *Commelina diffusa* (1381), *Fimbristilis miliacea* (1777), *Isachne globosa* (1817), *Limnocharis flava* (1821), *Monochorria vaginalis* (1569) and *Panicum repense* (1335).

When compared with the Pb bioconcentration capacity of *Calamus* sp that have been identified as a hyperaccumulators with a recorded BCF value of 1217, above aquatic species that occur in Sri Lanka can be also be considered potential phytoremediation agents for removal of lead through phytoextraction, particularly from sediment.

Solid Wastes Generation Potential and Composition in a Higher Educational Institute

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The estimation of waste composition is a vital part for the implementation of sustainable waste management system for any place. Estimation of waste composition for a six month period was carried out in the Faculty of Agriculture, University of Ruhuna, as an initial step for formulating a community based sustainable waste management system. All possible waste generation locations were categorized into four groups namely, Departments and Administration Buildings, Cafeteria, Quarters and Students' Hostels, based on the similarities of waste generation. Collected wastes in separate bins were further categorized manually, when required. In the first stage of the study, wastes were estimated according to their degradability. Waste estimation was carried out four times during six months period. Degradable and non degradable wastes in Departments and Administration Building per day per head were 64.4 ± 7.6 (mean \pm sd) and 7.4 ± 1.5 g, respectively. Degradable wastes collected in cafeteria were about 60.7 ± 1.7 g while non degradable wastes were quite low (0.19 ± 0.08 g). Relatively higher amount of waste were collected in quarters. It was 132.31 ± 57.13 g of degradable and 1.28 ± 1.15 g of non-degradable waste per head per day. Degradable and non-degradable wastes in Boys' Hostels were 60.38 ± 3.14 g and 4.53 ± 1.58 g respectively, while it was relatively higher in Girls' Hostels with 168.06 ± 11.52 g and 16.71 ± 2.92 g, respectively. Further categorizing of wastes such as paper, polythene, plastics, food wastes, glasses, metal, wood, textiles, rubber, animal wastes, hazardous wastes and fluorescents were carried out in one occasion (one week). Food waste was the highest in every section; in fact, it was relatively higher in quarters (152.27g) and hostels (114.22g) per head. Quite similar amount of discard polythene (about 0.30g) was collected in canteen and quarters. The reduction of use of lunch sheets in cafeteria, considerably, reduced the generation of waste polythene. Paper wastes generation was relatively higher in Department and Administration buildings (7.46g per head/day) rather than in other places. The results of this research reflect the types of wastes generated and composition in the higher educational institute and it could be used to formulate the common strategy for proper waste management in such, similar, institutions in Sri Lanka

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Phytoremediation potential of Iriyawetiya wetland at Kelaniya for heavy metal contaminated urban runoff

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Discharging wastewater, urban runoff and disposing dump waste in to natural wetlands is common practice in Sri Lanka. These effluents and urban runoff contain pollutants such as nutrients, toxic substances, oils and heavy metals. These pollutants in urban waste, when discharged in to the aquatic environment, accumulate primarily in water and sediment. Freshwater marshy wetlands are reported to possess the ability of reducing pollutants such as suspended matter, inorganic nutrients, heavy metals and pathogens in water.

Iriyawetiya wetland is a distant part of the Muthurajawela peat bog and situated close to the University of Kelaniya and in populous area (Kiribathgoda). This wetland provides an ideal site for the study on feasibility of using natural wet ecosystem in ecological engineering for wastewater treatment. Three replicates of water and sediment samples from ten sites including two main inlets, seven middle areas and one outlet area in the Iriyawetiya wetland with 1 m, 5 m and 10 m distance shoreline to middle were collected every two months. Except for Sn ($2.83 \pm 0.02 - 37.51 \pm 2.91$ mg/L), concentrations of heavy metals of Al ($68.06 \pm 0.03 - 4316.86 \pm 9.2$ μ g/L), Cd ($37.00 \pm 0.08 - 138.40 \pm 5.19$ μ g/L), Cr ($709.10 \pm 0.02 - 3031.60 \pm 0.08$ μ g/L), Cu ($66.0 \pm 0.01 - 1153.78 \pm 0.23$ μ g/L), Fe ($8.59 \pm 1.78 - 75.16 \pm 0.90$ mg/L), Mn ($1.61 \pm 0.005 - 6.35 \pm 0.009$ mg/L), Ni ($123.00 \pm 0.03 - 805.17 \pm 0.032$ μ g/L), Pb ($146.19 \pm 0.19 - 995.19 \pm 1.79$ μ g/L), Zn ($8.25 \pm 0.02 - 352.00 \pm 1.18$ μ g/L) in water samples taken from inlet areas were higher than that of taken from outlet area of the wetland. Iron ($8.59 \pm 1.78 - 75.16 \pm 0.90$ mg/L) was found to be the highest in concentration amongst metals studied in water samples collected from the wetland. Sn ($2.83 \pm 0.02 - 37.51 \pm 2.91$ mg/L) was the next high occurring heavy metal in water.

Except for Sn ($0.54 \pm 0.007 - 1.326 \pm 0.30$ mg/kg), concentrations of the other heavy metals Al ($4.44 \pm 0.47 - 14.97 \pm 0.33$ g/kg), Cd ($0.67 \pm 0.15 - 3.05 \pm 0.18$ μ g/kg), Cr ($70.49 \pm 0.07 - 108.55 \pm 0.01$ μ g/kg), Cu ($1.23 \pm 0.01 - 4.34 \pm 0.004$ mg/kg), Fe ($4.03 \pm 0.24 - 47.453 \pm 1.21$ mg/kg), Mn ($11.06 \pm 0.00 - 508.45 \pm 0.02$ μ g/kg), Ni ($1.75 \pm 0.31 - 34.93 \pm 0.34$ μ g/kg), Pb ($4.76 \pm 0.001 - 75.27 \pm 0.002$ μ g/kg) and Zn ($1.50 \pm 0.13 - 42.38 \pm 0.28$ μ g/kg) in sediment samples taken from the inlets areas were higher than those samples taken from outlet areas. Al ($4.44 \pm 0.47 - 14.97 \pm 0.33$ g/kg) was recorded at the highest level in sediments, while Fe ($4.03 \pm 0.24 - 47.453 \pm 1.21$ mg/kg), Cu ($1.23 \pm 0.01 - 4.34 \pm 0.004$ mg/kg) and Sn ($0.54 \pm 0.007 - 1.326 \pm 0.30$ mg/kg) were in fairly high amounts.

According to results obtained, the concentrations of metals in water (except Sn ($2.83 \pm 0.02 - 37.51 \pm 2.91$ mg/L)) gradually decreased when water moves through the wetland from inlet to outlet. But water samples in some sites taken from middle areas had moderate concentrations of metals. This could be due to the additions of house wastewater and dumping waste to the wetland. Results indicate the phytoremediation potential of natural wetlands, could be used in ecological engineering for wastewater treatment.

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Adsorption kinetics of sugarcane bagasse for selective removal of Cr (VI) and Cu (II) from aqueous solutions

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The Adsorption Kinetics for the simultaneous and selective removal of Cr(VI) and Cu(II) ions from aqueous mixture was investigated using sugarcane bagasse. Equal volumes of the laboratory prepared metal ion solutions of Cr(VI) and that of Cu(II), having the same initial concentration were mixed and used as test samples. Batch studies were performed at room temperature at three different initial concentrations of each metal ion to be present in the test sample: 10ppm, 30ppm and 50ppm. The available literature for the removal of each of these heavy metal ions when present individually in aqueous solutions was applied in these studies. Accordingly, water washed and sun dried sugarcane bagasse retained on 200 micron-mesh, was used for the study at a dosage of 0.4g/l of the test sample. No attempt was made to maintain a fixed pH as this involved addition of more chemicals adding to more contamination. Instead, the pH and remaining concentrations of the ions in the mixture after adsorption were monitored at various pre-set time intervals till equilibrium condition was attained. The pH of the test samples varied from 7.05 initial values to 8.09 at equilibrium, during all the batch studies. The study has revealed that the adsorbent had higher selectivity to Cu(II) ions in comparison to the Cr(VI) ions at the study conditions. The removal was faster and higher at low initial concentrations. The experimental results fit well with linearized Freundlich Adsorption Isotherm Model.

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Heavy metals in substrates of a freshwater wetland at Kelaniya

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Many natural wetlands function as successful remediation systems for the environmental impact due to industrial effluents and domestic effluents from urban and semi-urban areas. However, this protective function of natural wetlands often comes at the cost of substantial environmental degradation. Hence, wetland sediment analysis is essential in the assessment of the impact of industrial effluent discharge and in the determination processes of remediation of metals. The important fraction played by the sediments of wetlands is the regulation of nutrients (N, P, K) and other trace elements essential for plants as most bio-geo-chemical processes occur in the substrate of wetland to release nutrients and heavy metals.

Iriyawetiya wetland at Kelaniya is closer to the Kiribathgoda Township and it receives many effluents from urban runoff and industry. The urban runoff into wetland may include pollutants such as nutrients, toxic substances, poly-aromatic hydrocarbons, heavy metals, oils, pathogens and particles. A preliminary study showed that this wastewater carries appreciable amounts of toxic metals, especially heavy metals and their concentrations vary from place to place in the wetland. To determine the heavy metal concentrations in sediments of Iriyawetiya wetland, samples were collected from the inlets, outlets and the middle part of the wetland using a HDPE grab and metal concentrations in acid-digested samples were measured separately using an atomic absorption spectrophotometer.

Among the tested heavy metals Al, Fe, Cr, Zn, Cd, Mn and Ni (except Cu, Pb, Sn) were found in higher amounts in sediments at the inlet 01 area than the outlet area. Al, Cu, Sn, Cr, Zn, Cd, Pb, Mn and Ni in sediment of inlet 2 area were recorded comparatively lower values than the outlet area due to lesser loading of effluents in that area. The middle area of the wetland recorded higher amounts of all measured ten heavy metals than inlet 02. Al, Fe, Cu, Sn, Mn gave the highest values in the middle open areas of the wetland. This shows that pollutants in urban waste, when dispersed in to the aquatic environment, they accumulate primarily in water and sediments which accelerates the contamination of other water sources including groundwater and drinking water. Further it provides the mechanisms needed to be used for remediation methods of waste water using natural wetlands.

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A preliminary study on the heavy metal contents of two common fresh water marsh plants, *Pistia stratiotes* and *Limnocharis flava* in Iriyawetiya wetland at Kelaniya

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Ability of freshwater marsh plants to absorb heavy metals from water column and sediment has long been used for purification of water. Two common marsh plants, floating *Pistia stratiotes* (Diya gowa S.) and *Limnocharis flava* which grow attached to sediment or other organic substrata in Iriyawetiya wetland at Kelaniya were analyzed for five heavy metals, i.e. Lead, Cadmium, Manganese, Iron and Chromium with a view of characterizing the two species for their capacity to absorb these metals, that may qualify them as candidate species for ecological engineering techniques for wastewater purification.

In both species, except for Manganese, all the other metal content in roots (*Limnocharis flava*: Site 2: Fe- 77.825 ± 0.341 g/kg, Pb- 15.236 ± 1.215 g/kg, Cd- 0.2545 ± 0.0037 g/kg, Cr- 4.292 ± 0.389 g/kg; Site 3: Fe- 17.83 ± 0.1277 g/kg; Pb- 20.01 ± 0.384 g/kg, Cd- 3.0323 ± 0.0036 g/kg; Cr- 4.683 ± 0.701, Site 8: Fe- 21.265 ± 0.0428 g/kg, Pb- 5.961 ± 0.1366, Cr- 0.335 ± 0.0549; and *Pistia stratiotes* Site 3: Fe- 22.633 ± 0.0453 g/kg, Pb- 67.053 ± 3.9927 g/kg, Cd- 0.8656 ± 0.067 g/kg. Cr were higher than that of 0.338 the shoots. Manganese content in shoots (0.2427 - 0.6984 g per kg of plant dry weight) was greater than that of the shoots. Plants of both species that were growing near the inlets have contained more metals than plants of the same species growing in the middle part and near the outlet. Greater availability of these metals in the inlet may have led to greater accumulation of them in the plants and hence indicates a reduction in these metal content along the passage through the wetland. However, a slight increase in Pb and Cr content at the outlet would have resulted due to local additions.

When compare the extent of metal accumulation in the two species, the content of Pb, Mn and Cr in *Limnocharis flava* was greater than that of *Pistia stratiotes*; indicate their relative efficiencies of accumulating these metals. Iron and Cadmium accumulation, on the contrary, was greater in *Pistia stratiotes*.

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A PRELIMINARY STUDY ON THE PRESENCE OF HEAVY METALS IN AQUATIC PLANTS FROM A FRESHWATER WETLAND AT KELANIYA

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Aquatic plants are known for uptake of heavy metals from water and sediments. This very feature qualifies these plants as wastewater treatment agents. Capacity to absorb heavy metals however, varies among plants. Three aquatic plants, *Pistia stratiotes* (floating), *Limnocharis flava* (rooted) and *Ipomoea aquatica* (rooted plant with floating runners) from Iriyawetiya wetland at Kelaniya were tested for the presence of copper, zinc, lead, nickel, cadmium, manganese, tin and chromium in the plant tissues.

P. stratiotes, *L. flava* and *I. aquatica* plants were collected from the inlets, outlets and the middle part of the wetland and above heavy metal concentrations in acid-digested root and shoot samples were measured separately using atomic absorption spectrophotometer.

Tin (Sn) is the heavy metal that was found in relatively large quantities in all three plants, and *Ipomoea aquatica* recorded the highest content of Sn. Next highest occurrence was observed with Cr and the contents were highest in the rooted plant, *L. flava*, indicating that the sediment loads of Cr may be greater than the load in the water column. All other heavy metals occur in relatively low concentrations in all three plant species, indicating partly the lower loading rates of these heavy metals in Iriyawetiya wetland.

Occurrence of heavy metals in the roots was generally higher than that of the shoots. Greater Cr concentrations were recorded from roots of floating species, *P. stratiotes* and *I. aquatica* than the rooted species, *L. flava*.

Except for cadmium (in *P. stratiotes*) and manganese (in *L. flava* and *I. aquatica*), content of all the other heavy metals that occur in the plants that have been collected from the inlets was greater than that of those collected from the outlet, indicating the wetlands' capacity to remove heavy metals from water and sediment through plant uptake.

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